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Influencing Travel Behavior Via An Open-Source Platform
Phase 1: Implementation of OneBusAway

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16. Abstract

Developed and rural areas close to urban centers can use public transit as an effective strategy to reduce traffic congestion. Transit can improve mobility, accessibility, and quality of life of the residents of a region when perceived as reliable and efficient. However, unreliable or inefficient transit systems could lead to low ridership. Innovations in transit services are required to enhance the sustainability of urban centers and to increase the accessibility to jobs and other activities for people living in rural areas. Transportation professionals must develop strategies to improve the transit system and increase its ridership. One of these strategies is to provide users with real-time transit data through a real-time passenger information (RTPI) system. Transit users can then utilize this information to their advantage and comfort by reducing actual waiting times and the perception of waiting time at the stop. This solution increases ridership by improving the riders' experience when using this service.

This report represents phase one of a two-phase project. The main objective of phase one is to implement the open-source platform OneBusAway in the Integrated Transit System of Mayagüez (TIM, for its Spanish acronym) to have real-time information readily available for modeling and studying the impact on ridership. The methodology followed in this investigation was divided into four tasks, from literature review and understanding of OBA to its implementation. The preliminary results of this investigation show that OBA correctly identifies all the routes and stops of the system, and accurately estimates (predictions) for arrival time to specific stops while the buses are in operation. The main objective of phase two will be to explore how travelers choose between driving their own vehicles or using public transit, Transportation Network Companies (TNC) services, or other modes (e.g., carpooling, micro-mobility), and how to influence this behavior (i.e., increase transit ridership) using OBA.

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Table of Contents

Tables

Figures

List of Acronyms

ACS	American Community Survey
CBD	Central Business District
DRPU	Daily Rate Per Unit
DRT	Demand Responsive Transport
GIS	Geographical Information System
GPS	Global Positioning System
GTFS	General Transit Feed Specification
ITE	Institute of Transportation Engineers
MaaS	Mobility as a Service
MFA	Mayagüez Functional Area
MoM	Municipality of Mayagüez
NICR	National Institute for Congestion Reduction
OBA	OneBusAway
OS	Operating System
PRHTA	Puerto Rico Highways and Transportation Authority
PRPB	Puerto Rico Planning Board
PSTA	Pinellas Suncoast Transit Authority
RTPI	Real-Time Passenger Information
TOD	Transit-Oriented Development
TNC	Transportation Network Company
TIM	Transporte Integrado de Mayagüez (in Spanish, or Mayagüez Integrated Transit)
UPRM	University of Puerto Rico at Mayagüez
US	United States
USCB	United States Census Bureau
USF	University of South Florida

Abstract

Developed and rural areas close to urban centers can use public transit as an effective strategy to reduce traffic congestion. Transit can improve mobility, accessibility, and quality of life of the residents of a region when perceived as reliable and efficient. However, unreliable or inefficient transit systems could lead to low ridership. Innovations in transit services are required to enhance the sustainability of urban centers and to increase the accessibility to jobs and other activities for people living in rural areas. Transportation professionals must develop strategies to improve the transit system and increase its ridership. One of these strategies is to provide users with real-time transit data through a real-time passenger information (RTPI) system. Transit users can then utilize this information to their advantage and comfort by reducing actual waiting times and the perception of waiting time at the stop. This solution increases ridership by improving the riders' experience when using this service.

The Integrated Transit System of Mayagüez (TIM, for its Spanish acronym) is a bus service, free of charge to users, that operates urban and rural routes within the most populated areas of the Municipality of Mayagüez in Puerto Rico. In addition to the TIM service, the University of Puerto Rico at Mayagüez (UPRM) provides bus shuttle services connecting the student residential areas adjacent to the campus. The TIM serves 52 square miles of the municipality and has a population of 71,264 inhabitants. According to the FTA National Transit Database, TIM registered 188,407 Annual Unlinked Trips in the year 2019, or the equivalent to 725 daily trips.

OneBusAway (OBA) is an open-source solution to implement an RTPI system. A team of UPRM researchers working as part of a National Institute for Congestion Reduction (NICR) research project is currently assisting the Municipality of Mayagüez in implementing OBA in the TIM. OBA can provide real-time passenger information using a smartphone application. This information is provided by servers that use the General Transit Feed Specification (GTFS) files and the real-time vehicle location (i.e., Global Positioning System - GPS) to analyze and predict the arrival time of the transit vehicles at each bus stop.

This research project has two phases. The main objective of phase one is to implement the open- source platform OneBusAway in the TIM to have real-time information readily available for modeling and studying the impact on ridership. The methodology followed in this investigation was divided into four tasks, from literature review and understanding of OBA to its implementation. The preliminary results of this investigation show that OBA correctly identifies all the routes and stops of the system, and accurately estimates (predictions) for arrival time to specific stops while the buses are in operation. The main objective of phase two is to explore how travelers choose between driving their own vehicles or using public transit, Transportation Network Companies (TNC) services, or other modes (e.g., carpooling, micro-mobility), and how to influence this behavior (i.e., increase transit ridership) using OBA. This report corresponds to phase one of the NICR research project.

1.   Introduction

1.1 Demographic profile and market characteristics of Mayagüez

The Municipality of Mayagüez (MoM) is located on the west coast of Puerto Rico. The adjacent municipalities of the MoM are Cabo Rojo, Hormigueros, and San Germán to the south; Añasco and Rincón to the north, and Las Marías and Maricao to the east. The Caribbean Sea is located to the west of the MoM. The MoM is divided into 20 wards, including the uninhabited islands of Mona and Monito (Planning Board, 2018). The municipality's administrative center (Central Business District - CBD) is located at the *Mayagüez Pueblo* ward. Figure 1 presents the wards division of the MoM and Figure 2 presents Population Density the year 2012.

Figure 1. Wards Division of the Municipality of Mayagüez (MoM).

Figure 2. 2012 Population Density by Census Tract.
Source: Puerto Rico Planning Board (2018), MoM (2015).

Puerto Rico has eleven functional planning areas, as presented in Figure 3. The Puerto Rico Planning Board (PRPB) defines a functional area as a collection of interconnected municipalities that share various common aspects such as social, economic, and industrial development, among other characteristics that extend beyond the geographical features of the surrounding area. The Mayagüez Functional Area (MFA) is comprised of the municipalities of Añasco, Cabo Rojo, Hormigueros, Lajas, Las Marías, Maricao, Mayagüez, Rincón, Sabana Grande, and San Germán (shown in bright orange in Figure 3).

Figure 3. Geographic Limits of Puerto Rico's Functional Areas.
Source: Puerto Rico Planning Board (2018)

Within the Municipality of Mayagüez is located one of the major highways of Puerto Rico, PR-2, which connects the population to several service centers and commercial areas. Examples of these areas are the Mayagüez Medical Center, the Isidoro García Stadium, the Western Plaza Strip Mall, and the Mayagüez Mall. Major state roads, including PR-105, PR-108, and PR-106, also provide opportunities for commercial developments. Mayagüez is also home to the University of Puerto Rico at Mayagüez (UPRM), a public university with 12,136 students (UPRM, 2021).

The population of Mayagüez registered in the 2010 census was 89,080 inhabitants (OCPR, 2021). Preliminary results of the 2020 census indicate that the current population is reduced to 73,077 inhabitants, of which 98.7% are Hispanic or Latino. According to the United States Census Bureau-QuickFacts (USCB-QF, 2021), the current population density of the municipality is 940.8 inhabitants per square mile, compared to the estimated density in 2010 of 1,173 inhabitants per square mile. Comparing the 2020 census data with the 2010 census shows that the MoM has sustained a 19.7% reduction in population. Estimates made by the United States Census Bureau based on the American Community Survey (USCB-QF, 2021) indicate that the population is divided into 52.3% females and 47.7% males. The population between 18 and 65 years old corresponds to 58.6%, while the population over 65 years old corresponds to 24.8%. The average per-capita income estimated for 2019 was $10,994 US dollars, with 71.9% of the population aged 25 years and over having a high school degree or higher and 26.4% having at least a bachelor's degree. The presence and types of internet subscriptions in the household information for 2019 estimates that 63.6% of the population's dwellings have an internet data plan on their cell phones. This estimate is based on a sample of 28,649 households (USCB, 2021).

Regarding demographic characteristics, the population of Mayagüez has shown a tendency to decrease progressively. The population estimates for the MoM obtained from the US Census of years 2000, 2010, 2017, and 2018 are presented in Table 1. According to The Puerto Rico Planning Board, there was a 10.5% decrease in population between 2000 and 2010. The year 2018 demonstrated a population decrease of 4.4% compared to 2017.

Table 1. Population of Mayagüez from 2000-2018

Year	Population
2000	93,434
2010	89,080
2017	75,358
2018	71,986

Traffic Congestion Conditions in Mayagüez

There has been an increase in traffic congestion in almost every aspect from 1982 to 2019. In 2021, the Texas A&M Transportation Institute Urban Report (Lasley, P. 2021) presented continued congestion growth until 2020, when COVID-19 restrictions were

implemented. The travel time index for 1982 was 1.1; for 2000, 1.19; for 2019, 1.23; and lastly for 2020 1.09. The 2020 data is not an accurate representation of the reduction, if any, in congestion levels in the United States due to the presence of the pandemic.

The MoM is categorized as a Small Population Group in the US Census. According to Lasley, P. (2021), the average annual hours of delay per commuter experienced for the Small Population Group in the US in 2019 were 39 hours, whereas it was estimated as 42 hours for the MoM. Therefore, the annual hours of delay per commuter in Mayagüez were larger than the average for the "small population" group of cities in the US (less than 500,000 inhabitants).

Mayagüez is generally divided into the rural mountainous residential areas and the urbanized coastal area where most commercial activities are performed. The urban concentration of commercial activities has generated that most of the congestion in Mayagüez is located in the urbanized coastal area. Therefore, most congestion is concentrated along Highway PR-2 and the Pueblo ward.

Figure 4. State Highways of MoM.
Source: Puerto Rico Planning Board (2018).
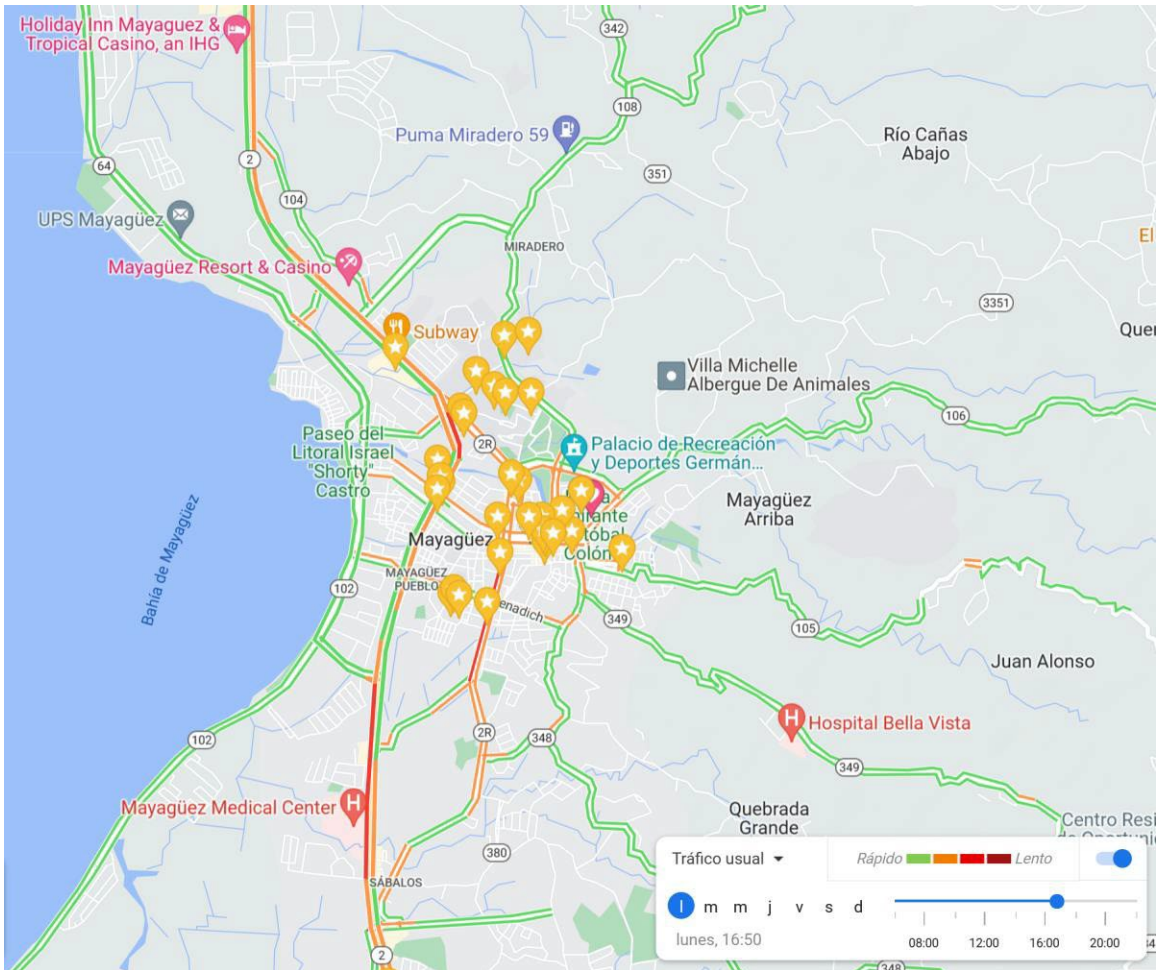
Figure 5. Traffic Condition in Afternoon Peak Hour.
Source: Puerto Rico Planning aBoard (2018). Google Maps.

Table 2. AADT for Principal Highways for Mayagüez from 2019.

Route ID	km	Direction 1	Direction 2	AADT
PR-2	147.6	To PR-109	To PR-64	44,562
PR-65	0.2	To PR-108	To PR-239	17,006
PR-108	13	To PR-406	To PR-352	2,368
PR-354	4.5	To PR-355	To PR-106	421
PR-102	2.49	To PR-3342	To PR-63	23,293
PR-102	1.65	To PR-3342 North	To PR-3342 South	25,754
PR-102	1.89	To PR-3342	To PR-63	26,660
PR-102	2.65	To PR-3342	To PR-63	24,742
PR-102	3.3	To PR-3342	To PR-63	21,182
PR-239	0.65	To PR-65	To PR-2	24,232
PR-2	146.83	To PR-64	To PR-342	49,541
PR-2	153.05	To PR-3108	To PR-239	42,265
PR-63	0.16	To PR-2	To PR-102	15,736
PR-102	0.58	To PR-2	To PR-64	10,769
PR-102	1.01	To PR-64	To PR-3342	23,762
PR-2	149.5	To PR-64	To PR-104	33,965
PR-2	150	To PR-64	To PR-104	37,499
PR-2	150.85	To PR-64	To PR-104	43,627
PR-2	152.2	To PR-104	To PR-102	38,016
PR-2	152.7	To PR-102	To PR-3108	38,197

Source: PR, E. (2021).

The data presented on Table 2 is data form the Puerto Rico Institute for Statistics. The AADT presented are form 2019 for the principal highways for the MoM. There is no data available about trip purposes, origin-destination patterns, or private motor vehicle usage (other than traffic daily volumes) in the MoM. In the absence of such data, it is difficult to establish a link between a possible shift in transit ridership and a corresponding reduction in traffic congestion on the highway network. Implementing the OneBusAway platform in the TIM as a transit passenger information improvement project should improve the passenger's experience, and while it might not significantly reduce congestion in the municipality on the short or medium term, presents an opportunity to acquire data about transit usage and ridership in the MoM that can be analyzed and used to propose public policy enhancements that could improve transit and reduce traffic congestion.

1.2 Description of the Integrated Transit System of Mayagüez (TIM)

The TIM provides a free-of-charge service of bus routes in the MoM. TIM started operations in 2012 to provide accessible public transportation to the Mayagüez Pueblo's ward and surrounding areas (i.e., downtown). The transportation system of an area is strictly tied to the social-economic development of the place itself. Following the definitions developed by Manheim (1979), the system is described utilizing three essential variables: the activity system (A), comprising the patterns of socio- economic activity; the transportation system (T), which includes the physical and operational aspects of the transportation system; and the flow patterns (F), including volumes of cargo or people generating trips along the routes from origin to destination. A visual representation of the connection between these three variables can be observed in Figure 6. The Flow Pattern in the Transportation System and the Activity System.
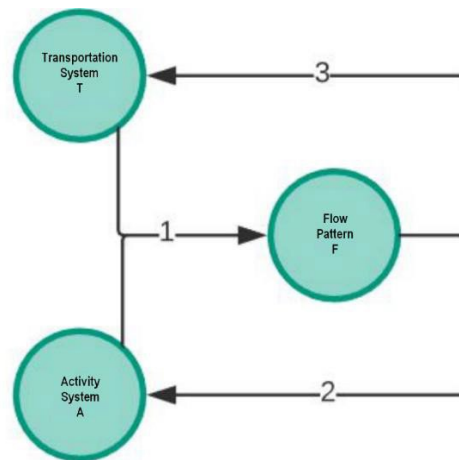
Figure 6. The Flow Pattern in the Transportation System and the Activity System
Source: Manheim (1979)

1.3 Activity System (A) of the Municipality of Mayagüez

The activity system is defined by the area's social, economic, and political characteristics (Manheim, 1979). This information is then correlated with the region's features and its inhabitants, such as demographics and the social-economic level of the population. The activity system is the most critical component in defining the transportation demand. The activities, their location, and the travelers' decision-making process generate the flow pattern observed in the transportation system. The activity system is divided into two components: the social-physical components and the organizational components (González, 2000). A brief description of the Activity System components is presented in this section.

The social-physical components pertain to the physical layout of the locations that may attract some form of activity. Residential areas, places of work, and recreational areas are some examples (González, 2000). The activities could be characterized as industrial, commercial, financial, tourism, and institutional, just like the demographics can be affected by the population, gender, age, family size, and income.

There is a large quantity of residential and commercial areas in the MoM. Examples of commercial areas include the Mayagüez Mall and Western Plaza. Besides commercial and residential developments, there is also a significant quantity of institutional buildings. Schools, churches, hospitals, and public plazas are some examples that can be observed in Figures 4 and 5. The MoM registers 30.3% of the total employment of the MFA, according to the Planning Board (2018).
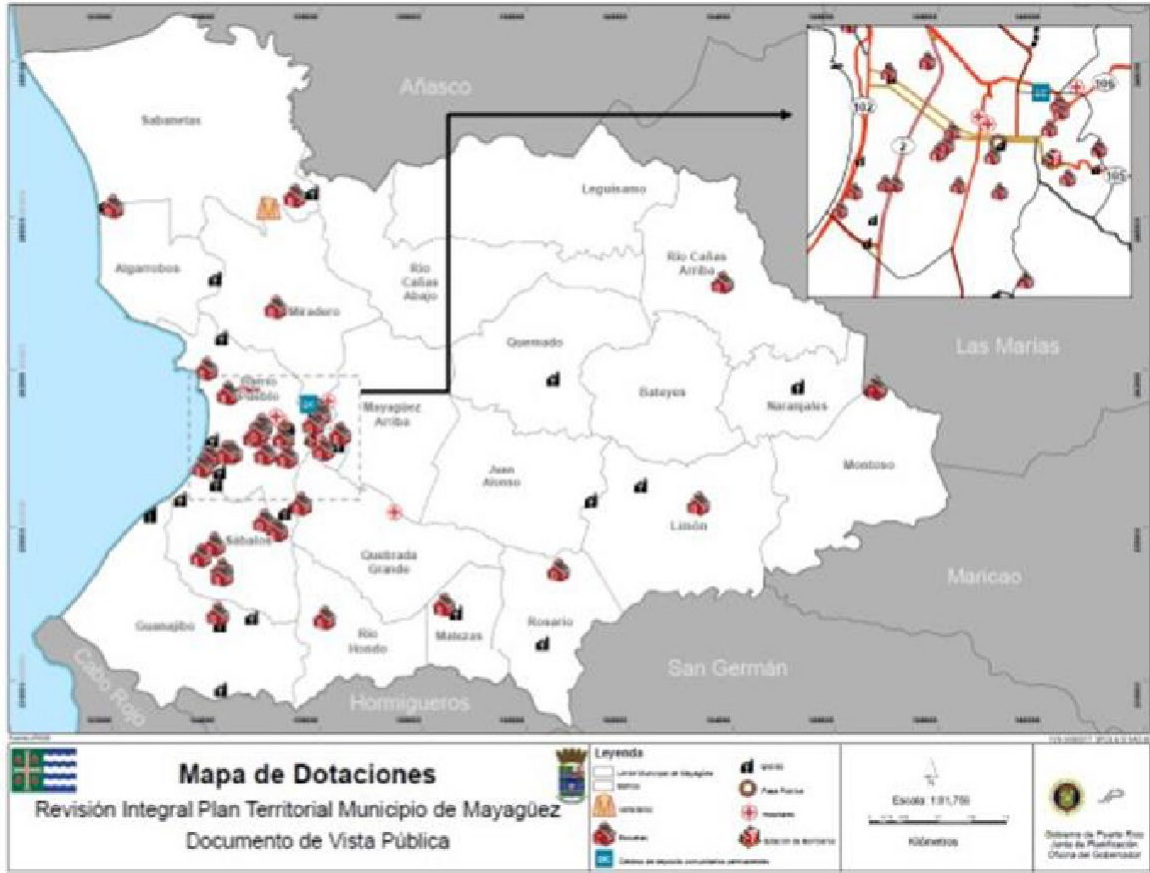
Figure 7. Location of the Endowments of the Municipality of Mayagüez.
Source: Puerto Rico Planning Board (2018)

The educational area can be primarily described by the University of Puerto Rico at Mayagüez (UPRM), the Pontifical Catholic University of Puerto Rico in Mayagüez, the Antilles Adventist University, and the National University College (NUC). Examples in the medical area include the Mayagüez Medical Center, Yaguez Clinic, Veteran Hospital, Bella Vista Hospital, San Antonio Hospital, Perea Hospital, and several medical office buildings. Examples of recreational areas include the Recreational and Sports Palace Wilkins Vélez Ramírez, Litoral Park, Proceres Park, Beaz and the Isidoro García Stadium. There is the Yagüez Theater, Caribbean Cinema theaters, and the Regional Cultural Institute Office in the cultural area. Public security areas include the Mayagüez Police Station, the Regional Civil Defense, and the Mayagüez Justice Center (Planning Board, 2018).

(a) University of Puerto Rico at Mayagüez

(b) Catholic University of Puerto Rico

(c) Mayagüez Medical Center

(d) Recreation and Sports Palace

(e) Yagüez Theater

(f) Litoral Park of Mayagüez

Figure 8. Main Trips Attractions on the of MoM.
Sources: Fundación Alumni Colegial (2019), Puerto Rico PUCPR (2019), Center (2019), Mayagüez (2019), Pinterest (2019), Scape (2019)

Regional government offices are assigned to the following: Department of Human Resources and Environment, State Insurance Fund Corporation, Authority of Public Buildings, Department of the Family, Department of Transportation and Public Works, and Department of

10

Education (Planning Board, 2018). Federal government services in the MoM include the Department of Armed Forces Recruitment and Federal Services, and the Veterans Clinic (Planning Board, 2018).

Nevertheless, the Mayagüez population is not the only factor that contributes to generating congestion in the city. Mayagüez is the center of economic activity for the whole western region. Therefore, its transportation network receives the influx of traffic from neighboring municipalities and the traffic that travels between the south and north of Puerto Rico. Being the center of the regional economic activity, the implementation of a Real-Time Passenger Information System will benefit the transportation users of the whole region.

The organizational components of the Activity System incorporate the people and the organizations that make trips using the transportation system's physical elements. This component includes the Government of Mayagüez, the UPRM, and the Puerto Rico Highways and Transportation Authority (PRHTA) as the prominent institutions.

Transportation System (T)

Manheim (1979), as stated by González (2000), indicated that the transportation system consists of the same two components as the activity system: the organizational and the physical components. The organizational component consists of the operational organizations, both public and private, and the procedures used to plan, design, construct, and operate the physical components. The physical components are the technology, networks, links, vehicles, and operational policies.

For the MoM, the transit system is represented by the Integrated Transit of Mayagüez (TIM) and other transportation systems that operate in the municipality. There are two taxi companies, "Taxi White" and "Taxi Pueblo," as well as TNC services provided by Uber. Since 2019 the company Skootel has provided rental scooters in the central town and university areas.

Technologies within this component exist to satisfy the demand in a way that was previously not available. TIM is one of these possibilities as it contains routes that expand to most of the municipality. Some of the stops have amenities such as those presented in Figure 9(a). The system also has signs that indicate the routes and stops, as shown in Figure 9(b). In addition to the route signs, the departure time of all rural routes is exhibited at the main terminal located in the *Barcelona* neighborhood in the CBD.

The network characteristics depend on the shape and geography of the municipality. The form of the urban area with a block system allows the development of a reticular network. However, in rural areas, where the geography of the municipality defines the roads, the network is radial, with the main terminal at the city center. The radii extend towards the rural areas for each of the roads that cover the municipality. The TIM route network has a predominantly radial structure with lines that extend to and from the rural neighborhoods to the system terminal located in the downtown area.

(a) Bus Stop and Bench Located at the City Square
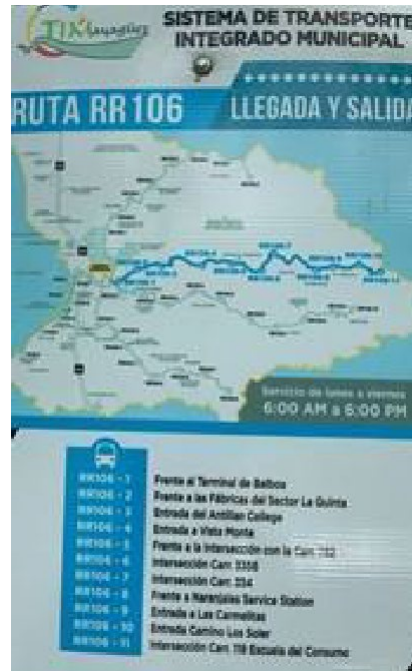
b) Information Sign for Route RR106

Figure 9. TIM Bus Stop and Sign.

The TIM network is composed of four urban and six rural routes. The urban routes of the TIM system provide circulatory or shuttle service to the Mayagüez Pueblo ward or downtown area. The four routes 1, 2, 3, and M (El Maní Neighborhood) of the TIM urban subsystem can be observed in Figure 10. Three of the urban routes (1, 2, and 3) provide circulatory service inside the Pueblo ward. The M route provides service along the highway PR-102 connecting the *El Maní* ward, located to the north side of the municipality. The operation of the urban routes is based on their established frequency.
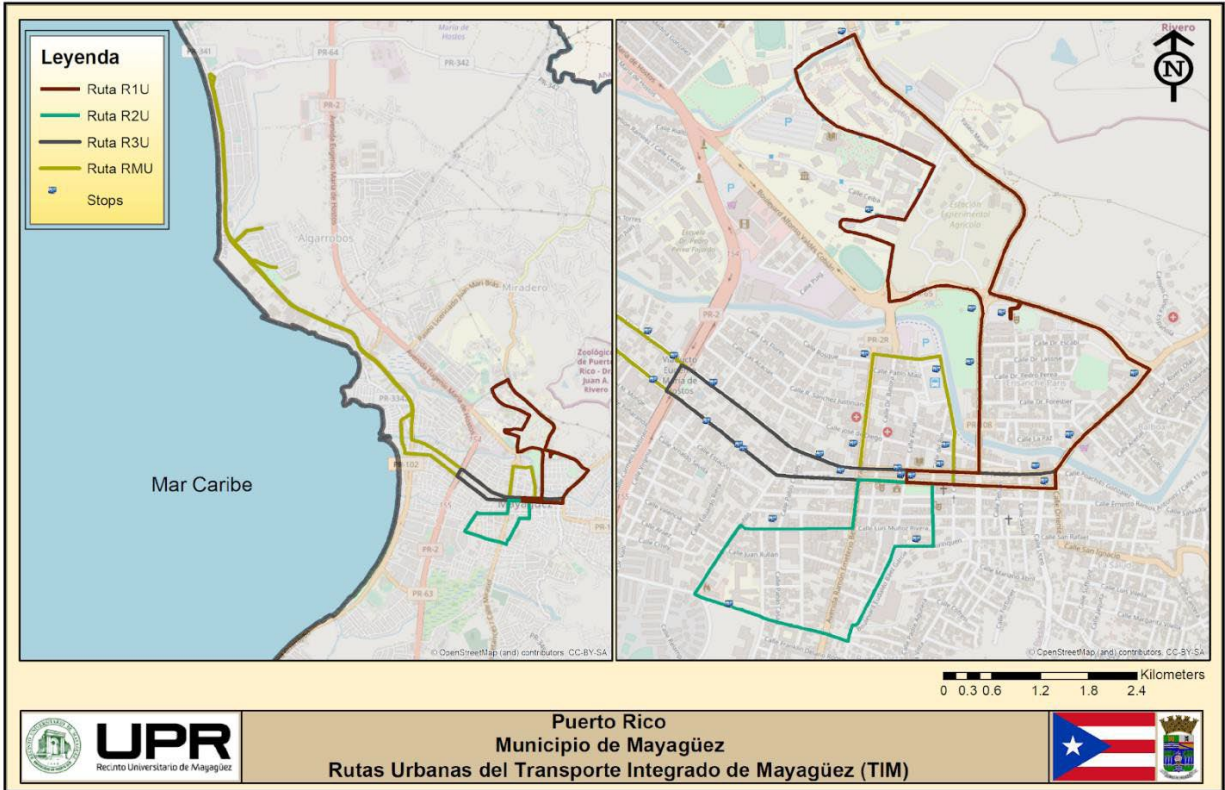
Figure 10. TIM Urban Routes.
Source: TIM Mayaguez (2019)

The six routes in the rural sub-system originate in the main Barcelona terminal located in the CBD and reach the furthest limits of the municipality. This sub-system has the distinct characteristic that it connects the rural areas of the municipality to the more densely populated town area. In addition, and different from the urban system, there is an established departure schedule for each bus that exits the main terminal. The itinerary is presented in a table and further described in section 1.4.2 of this report.
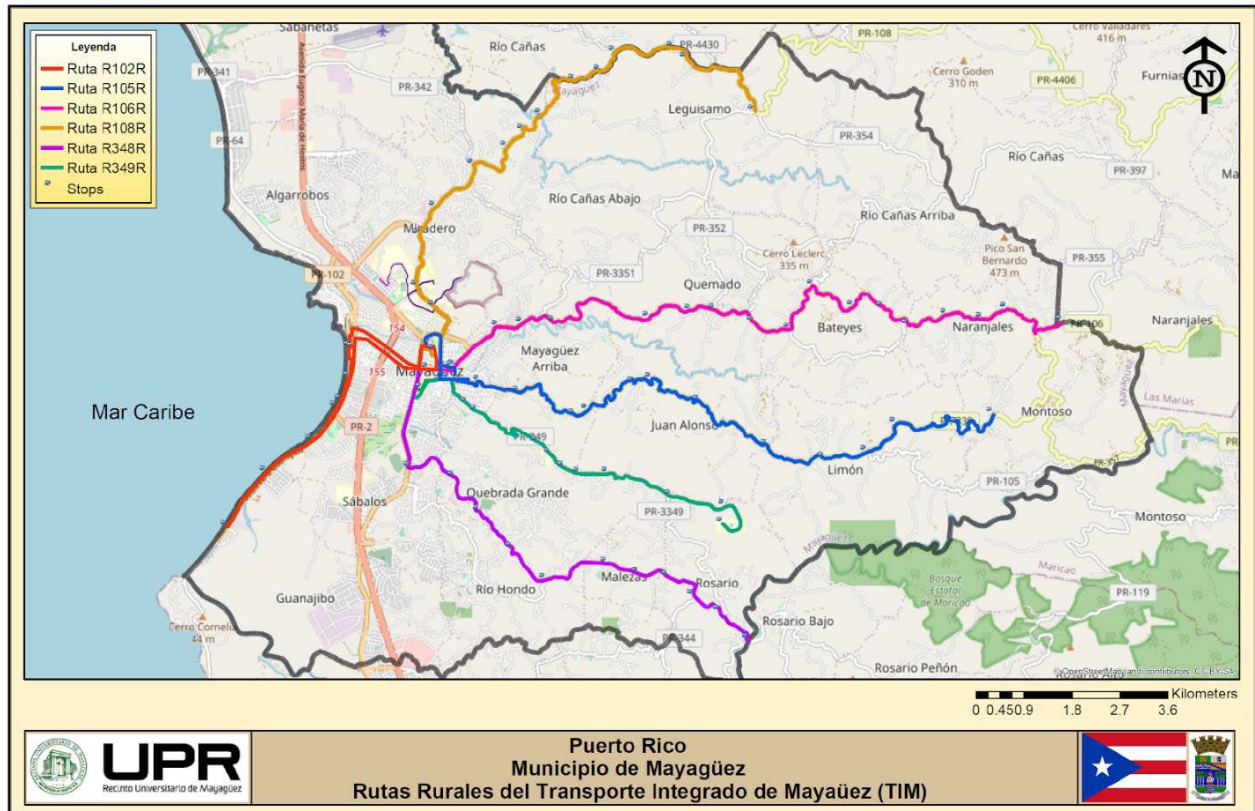
Figure 11. TIM Rural Routes
Source: TIM Mayaguez (2019)

In addition to the TIM system operated by the municipality, the UPRM operates a separate bus service directed to the academic community. The UPRM transit service is focused on serving the campus adjacent areas for the students and university staff. Table 3 shows the number of bus stops and buses that operate along each route.

Characteristics of the Links

The TIM buses loop around the urban streets, rural roads, and the local roads that pertain to the UPRM. The characteristics of the highways used for each system are described below.

Urban Link Characteristics

Most urban roads are one- or two-lane roads with sidewalks and lateral parking spaces (i.e., on- street parking). Routes R1R, R2R, and R3R have similar characteristics. These three routes are interconnected by the principal urban roads of Méndez Vigo and Candelaria Streets. These two streets run parallel east-west but in opposite directions, connecting the city center with the coastline. On these streets, various routes share their main terminal and multiple stops. The Méndez Vigo Street is a two-lane one-way arterial street that runs east to west, with sidewalks on both sides and on-street parking on both sides. Candelaria Street has the same road characteristics as Méndez Vigo Street, but runs west to east. Both streets also intersect with highways PR-2 and PR-102.

Route R1U runs along part of the highway PR-108 and Martínez Nadal street. Routes R2U and R3U offer stops that are close to the main activity attractions in the CBD, such as the Government Center, "Plaza del Mercado," Hostos High School, the US Postal Service Office, banks, the MayaWest Hotel, and the historic site of Plaza Colón. Route number R3U offers stops to connect a main supermarket, UPRM, the neighborhood of París, and other attractions. Figure 12 presents the cross-section of some of the roads in the urban sub-system.

(a)Méndez Vigo Street

(b) Candelaria Street

(c) Martínez Nadal Street

(d) State Highway PR – 108
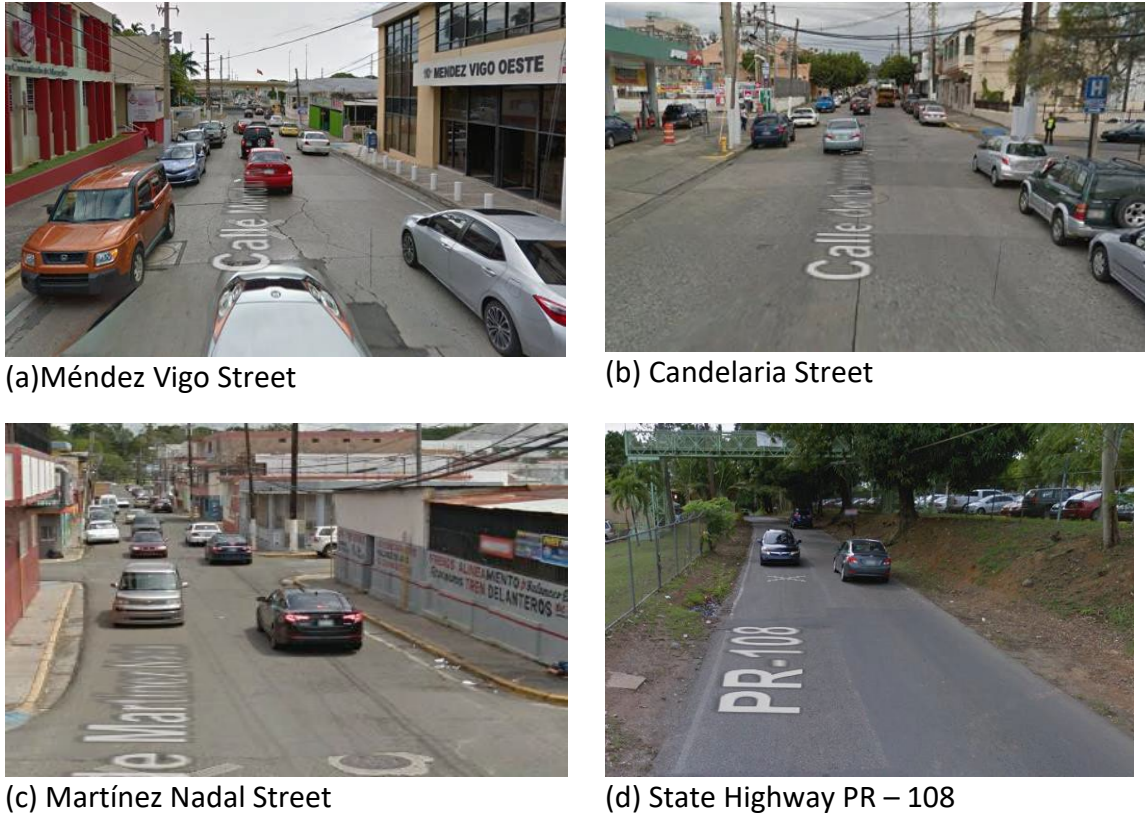
Figure 12. Cross-sections for TIM's urban network.

Rural Link Characteristics

The TIM rural sub-system operates on the following highways:

- **PR-102:** Route R102R runs on this highway, starting at Mar y Sol Avenue and finalizing at the intersection with PR-318.
- **PR-105:** Route R105R utilizes part of this road. Highway PR-105, also known as Luis Muñoz Marín Panoramic Route, starts at PR-102 and finishes at PR-120.
- **PR-1*06:* Route R106R runs on this highway, also known as the Mayagüez-Las Marías highway. The route starts at the intersection with highway PR-65 and ends at the intersection with highway PR-120.
- **PR-108:** Operating on this road is Route R108R. PR-108 or Mayagüez-Añasco starts at San Rafael street and ends at the intersection with road PR-4406.

- **PR-348:** Operating on this road is Route R348R. PR-348 starts at the intersection Betances Street (former Post St.) and ends at the intersection with road PR-330.
- **PR-349:** Operating on this road is Route R349R. PR-349 or Road Las Mesas starts at Manati street and ends at CROEM School.

The TIM uses three different transit vehicles, with one or two models for each sub-system. The rural routes operate with Ford model Turtle Top Terra buses. This type of bus has a capacity of 20 passengers. The model can be observed in Figure 13(a). The buses on the urban routes are "vintage" tramway-type models, as shown in Figure 13(b). This type of vehicle has a capacity of 15 seated passengers but increases up to 25 passengers when allowing stand-up passengers. The vehicles on the UPRM system are a combination of 20-passenger buses and van-type vehicles with a capacity of 10 riders, as shown in Figure 13(c).

(a) Vehicle for TIM Rural Routes   (b) Vintage Bus for TIM Urban Routes

(c) Vehicle for the UPRM Trolley Service

Figure 13. Bus Types for Transit Services in the MoM

Organizational and Operational Policies

This section describes the organizational and operational policies for all three transit services. The urban TIM is administered and operated by the Economic Development and

Planning Office of the Municipality of Mayagüez. The service operates Mondays through Fridays from 6:00 am to 6:00 pm. The TIM rural service is also administered by the Economic Development and Planning Office of the municipality but is operated by Sonnell Transit. Sonnell Transit is a local private company dedicated to providing transportation services in Puerto Rico (Sonnell, 2021). The rural TIM sub-system also operates on weekdays from 6:00 am to 6:00 pm. The service has a total of 16 drivers, two for each shift of six hours and 30-minute breaks for each vehicle. The drivers must retrieve the vehicle at the base of operations (or depot) and move the vehicle to the Barcelona Bus Terminal to begin the shift at 6:00 am. After the last scheduled trip, the driver must return the vehicle to the base of operations. Between scheduled trips, the drivers must clean and sanitize the vehicles before the next trip. Each vehicle is routinely maintained based on individual maintenance needs. The number of bus stops and buses that operate along each bus route are shown in Table 3.

Table 3. Bus Route Information

Route	Sub-System	No. Stops	No. Buses	Operation Type
R1U	TIM Urban	8	1	Frequency
R2U	TIM Urban	4	1	Frequency
R3U	TIM Urban	8	1	Frequency
M	TIM Urban	41	1	Frequency
R102R	TIM Rural	10	1	Schedule
R105R	TIM Rural	16	2	Schedule
R106R	TIM Rural	18	2	Schedule
R108R	TIM Rural	15	2	Schedule
R348R	TIM Rural	13	1	Schedule
R349R	TIM Rural	14	1	Schedule
RUMI	UPRM	8	1	Frequency
RUMP	UPRM	7	1	Frequency
RUMT	UPRM	8	1	Frequency
RUMZ	UPRM	7	1	Frequency

The Rural TIM operates on a schedule programmed by the Planning Office of the Municipality of Mayagüez. The departure itinerary shown in Table 4 corresponds to all rural routes. Routes R- 105, R-106 and R-108 have two vehicles (A and B) to cover each route. The other three routes have one vehicle each. Both transit services are provided free of cost to users.

Table 4. TIM Rural Schedule

TIM Schedule									
Period	**R-102**	**R-105**		**R-106**		**R-108**		**R-348**	**R-349**
		A	B	A	B	A	B		
AM	6:00	6:00	6:30	6:00	6:30	6:00	6:30	6:00	6:00

TIM Schedule									
	7:05	7:58	8:28	7:30	8:00	7:22	7:52	7:15	7:00
	8:10	10:11	10:41	9:25	9:55	9:07	9:37	8:55	8:10
	9:30			11:00	11:30	10:29	10:59	10:20	9:40
	10:35								11:00
PM	12:25	12:49	1:19	1:10	1:40	12:31	1:01	12:25	12:55
	1:30	2:29	2:59	2:45	3:15	1:53	2:23	1:50	2:15
	2:35	4:24	4:54	4:40	5:10	3:30	4:00	3:30	3:30
	3:55					4:52	5:12	4:55	5:05
	5:00								

The UPRM bus system is operated by university staff. The UPRM service operates Mondays through Thursdays from 6:00 am to 10:00 pm, and from 6:00 am to 6:00 pm on Fridays. During the weekends, the service is not available. The bus service is provided free of cost to users.

Flow Pattern for Transportation System (F)

The flow pattern comprises the origins, destinations, and volume of passengers transported by each transit system. The information on passenger volumes will be determined in the second phase of this project. The following information is a summary obtained from the 2019 Annual Agency Profile of FTA.

The TIM service area has 52 square miles and serves 71,264 people. There are 188,407 Annual Unlinked Trips (UPT) which means approximately 725 trips per day. The TIM provided 300,401 Annual Vehicle Revenue Miles (VRM) and 35,169 Annual Vehicle Revenue Hours (VPH) in 2019.

2. Literature Review

The literature review for this research included congestion reduction strategies using transit, strategies on improving transit systems, and the description of the open-source platform OBA.

2.1 Transit and Congestion Reduction

Congestion is not just a detrimental part of surface transportation; the harmful environmental effects that large-scale congestion has are a cause for concern. This, in turn, is a significant contributor to greenhouse gas emissions and potentially a contributor to climate change (Beaudoin, 2016). The National Institute for Congestion Reduction (NICR) is dedicated to utilizing innovative technologies and strategies to reduce congestion in cities. While the implementation of transit is not a new strategy, there is an increase in new and innovative transit improvement strategies that strive to create an incentive for travelers to utilize public transportation as their selected mode of transportation daily.

Transit has a direct effect on the reduction of congestion. This was estimated using the Los Angeles transit strike data between October and November in 2003, which resulted in an increase in highway travel delays by 47% (Anderson, 2013). Therefore, if improvements in a low ridership transit system can be made so that the ridership increases, highway congestion (and travel delay) can be reduced. Innovative advances in transit targeting the rise in ridership and attracting more people to utilize transit for their daily trip, will mean fewer vehicles on the road and reduced traffic congestion.

2.2 Transit Improvement Strategies

One of the sources of the congestion problem is the ever-growing demand for transportation: as the population of a city grows, so does the need for transportation. As a response to the growing demand, transportation professionals have developed strategies to improve transit systems. This section discusses strategies that could be implemented in the transit system of Mayagüez, the TIM system, intending to increase ridership.

Demand Responsive Transport (DRT)

Demand Responsive Transport is a passenger-oriented transit improvement strategy with a flexible non-fixed transit route that provides curb-to-curb pickups and drop-offs (HERE Mobility, 2020). It is usually utilized in covering the first or last mile of a traveler to complement the main segment of travel in a mass transit system. Such a service would require prior planning on the part of the customer. This strategy is utilized to target low-density communities and people with disabilities. Areas with low density have a difficult time using transit services. To provide accurate coverage, the operator would need to extend the route. These extensions, however, can create a paradox because extending the route for only a few passengers would increase the travel time for the whole route. Therefore, implementing the DRT system for the last mile or first mile could attract more users to the transit system.

This service can expand the coverage of the transit system by flexibly filling the gaps between the existing systems and their routes. This strategy also increases the social equity of the region by increasing the mobility service for the underserved population, effectively acting as an extension of the route. Coordination of demand response with other transit services could result in inefficient use of resources. DRT has a higher operational cost than fixed-route services. There should be a comprehensive analysis to determine if the implementation is viable.

The Pinellas Suncoast Transit Authority (PSTA) in Tampa, Florida established a one-of-a-kind partnership to implement DRT with Uber in 2018. Later, they included United Taxi and Wheelchair Transport (Watkins et al., 2020). This partnership between PSTA and private transportation companies was formed to incentivize transit use. Direct Connect is a website created to take advantage of the partnership. Through Direct Connect, a user can get a discount when utilizing one of the three private transport companies previously mentioned for first and last-mile trips.

Mobility as a Service (MaaS)

The Institute of Transportation Engineers (ITE) defines MaaS as a system that is not owned by consumers but used as an on-demand service (Zmud, 2019). It offers easy access in the most appropriate transport mode or service bundled up for the user's needs. This transit improvement strategy targets the specific need of the users adapting to the diverse needs of travelers. MaaS creates seamless, high-quality transport services that could improve transit ridership by connecting and allowing the user to have access to all the transport modes.

This transit strategy allows users to plan trips across different modes of transportation seamlessly. For example, a user living in the outskirts of the city could use Maas services to take a taxi or similar service to a bus stop, take the bus to the city, then utilize a bike-sharing or e-scooter option to travel the last two blocks to get to work, all from one service provider.

The most significant concern for MaaS implementations is that this service could inadvertently lead to exclusion (Pangbourne et al., 2018). Therefore, the planning process must be cautious so that the implementation of such systems does not exclude any social groups.

In Helsinki, Finland, there is a MaaS application called Whim (Whim, 2021). Whim is an internationally awarded Finnish mobility application that allows users to book and pay for all their trips, one trip at a time or with a convenient seasonal order. Figure 14 shows the variety of plans that offer this application and their costs.
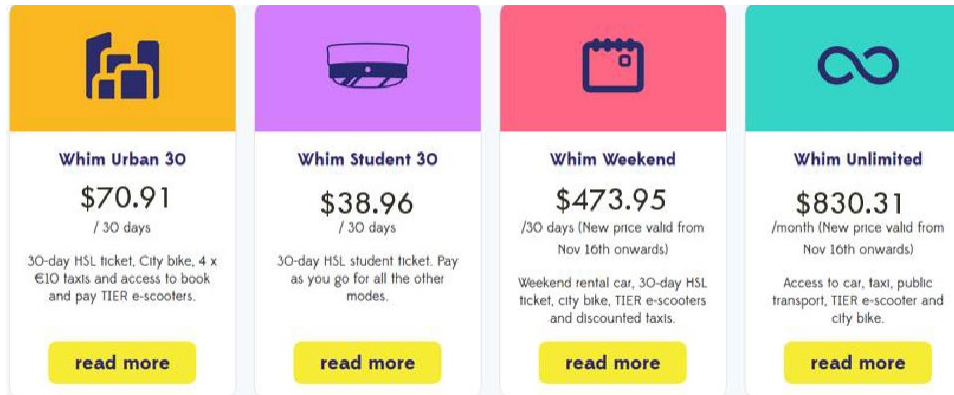
Figure 14. Demonstration of Whim and the Cost of its Services.
Source: https://whimapp.com/

Placemaking

Placemaking is one of the most straightforward and shared strategies for improving the ridership of a transit system (Projects for Public Spaces, 2016). Placemaking includes planning the bus routes to coincide with points of interest, like plazas or shopping centers. By creating places where people come together, the system can create localized points to develop socio-economic activities.

Placemaking adds to the cultural and aesthetic appeal of a city. By developing attractive locations for tourism and social activities, people can walk and discover the city (Domino et al., 2016). This, in turn, is directly connected to the transit system of a city. If there is an incentive to walk in some areas and there is an available transit system that services this area, people would be motivated to use it. These points of interest can also be relatively inexpensive to construct. An example of placemaking is shown in Figure 15, where a place was made more attractive simply by adding some appeal, in this case, several umbrellas in a variety of colors.

Figure 15. Example of Placemaking.
Source: Kelly, S.N. (2016).

Figure 15 shows the Umbrella Street of Portugal; this idea was also implemented in Puerto Rico in front of the governor's office. It succeeded in attracting many people to the site. While placemaking is a relatively inexpensive strategy, these points of interest can lose their appeal quickly and, therefore, should be frequently maintained.

Transit-Oriented Development

Transit-oriented development (TOD) is an urban planning strategy utilized to improve transit ridership. While the MaaS strategy focuses on the user and their need in transportation across all modes, TOD focuses on the transit system and how to create a transit-oriented environment surrounding the transit system. This strategy has become a growing trend of making compact, walkable, pedestrian-oriented, mixed-use communities centered around high-grade transit systems. This strategy is targeted at reducing the dependence on personal vehicles (Gandy et al., 2017)

TOD allows residents to live, work, and play in the same area that provides access to better entertainment or recreational activities, thereby stimulating the local economy to revitalize urban areas. There are also the benefits of reducing the dependency on driving that help reduce congestion. Reduced congestion also helps with reducing carbon footprint.

A situation that typically affects the implementation of TOD is the negligence of pedestrian access. In Mayagüez, the TIM system has been promoted in recent years, but pedestrian access can improve.

An example of the implementation of TOD strategies can be found in Portland, Oregon. This city has taken many steps to implement TOD. Starting from 1973, Oregon has taken steps to meet the goals of creating a city with transit. Figure 16 shows a timeline that presents the steps taken by the city of Portland to implement TOD. This figure summarizes the information found in the literature about the implementation of TOD strategies in Portland. As presented in Figure 12, Portland, Oregon is still making strides to reach its goals (Gandy et al., 2017). The perceived benefits of implementing TOD are shown in Figure 17 (TOD Institute, 2016)
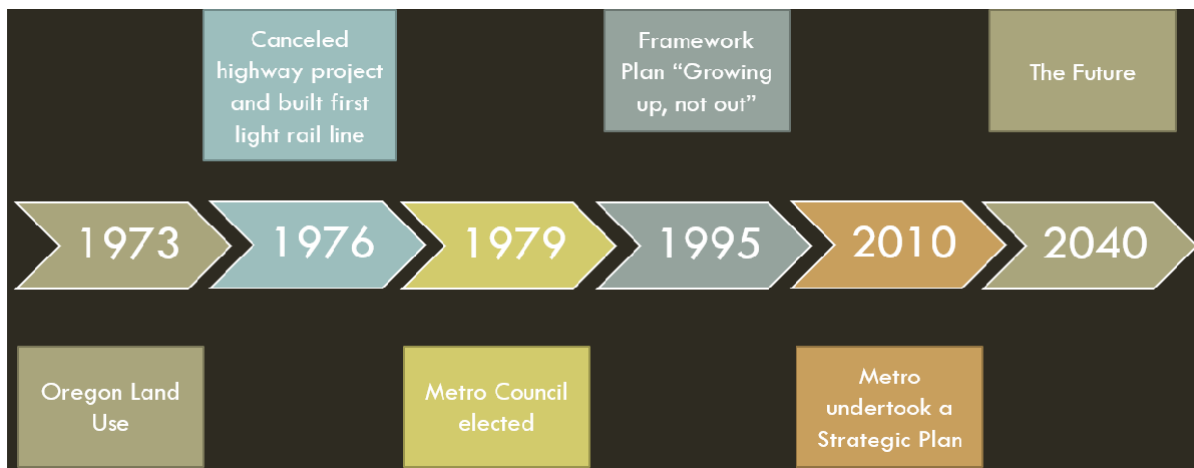
Figure 16. Timeline for TOD implementation in Portland Oregon.

BENEFITS OF TRANSIT ORIENTED DEVELOPMENT

Americans believe transit oriented development provides an array of benefits ranging from lifestyle to environmental to economic.

57% — Reduce dependence on driving
46% — Allow residents to live, work, and play in the same area
44% — Reduce the area's carbon footprint or negative impact on the environment
43% — Provide access to better life services
43% — Stimulate the local economy
42% — Provide better access between urban and suburban areas
39% — Provide access to better entertainment or recreational services
37% — Provide access to better jobs
30% — Revitalize urban areas

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Figure 17. Benefits of TOD
Source: TOD (2016)

Improved Rider Experience

Providing users with real-time transit data is one way to increase ridership by improving the rider's experience (Gooze, 2013, Brakewood et al., 2015). Passengers can use this information to their advantage and comfort. By providing more accurate information, users can better plan their trip.

Benefits of implementing a Real-Time Passenger Information (RTPI) strategy in a transit system include reducing wait times at the stop, reducing the perception of wait time, increased efficiency in users' trip planning, and increase riders' satisfaction. These systems often look like the one shown in Figure 14.

Most real-time transit information systems require expensive third-party contracts to implement. One thing to consider is that these costly arrangements may not be feasible for budget- constrained transit agencies (Canales, 2018). Therefore, these agencies cannot provide real- time information or obtaining valuable transit data using third-party contracts. For example, a third party could withhold transit data from the operational agency, claiming that it is their property. The image in Figure 18 is an example of a traditional RTPI system.

Figure 18. Example of RTPI System.
Source: NYC DOT

However, other options can be utilized to provide this service. One such option is to implement an open-source real-time transit information platform such as OBA. Since OBA is an open-source platform, all the data collected through the platform can be utilized by the transit agency to improve their services further. Also, this platform is relatively inexpensive to implement in comparison to third-party contracts. Figure 19 shows the appearance of the user interface of the OBA smartphone application and examples of the information provided to the users; it presents three examples of screenshots of OBA. Screenshot (a) shows how route and prediction information is presented in OBA; screenshot (b) demonstrates how schedule information is presented alongside the prediction information; and screenshot (c) depicts the users' location and distance from the nearest stops in the area.

| (a) Route and Prediction Information | (b) Schedule Information along its Prediction | (c) User's Location and Distance to Nearest Bus Stop |
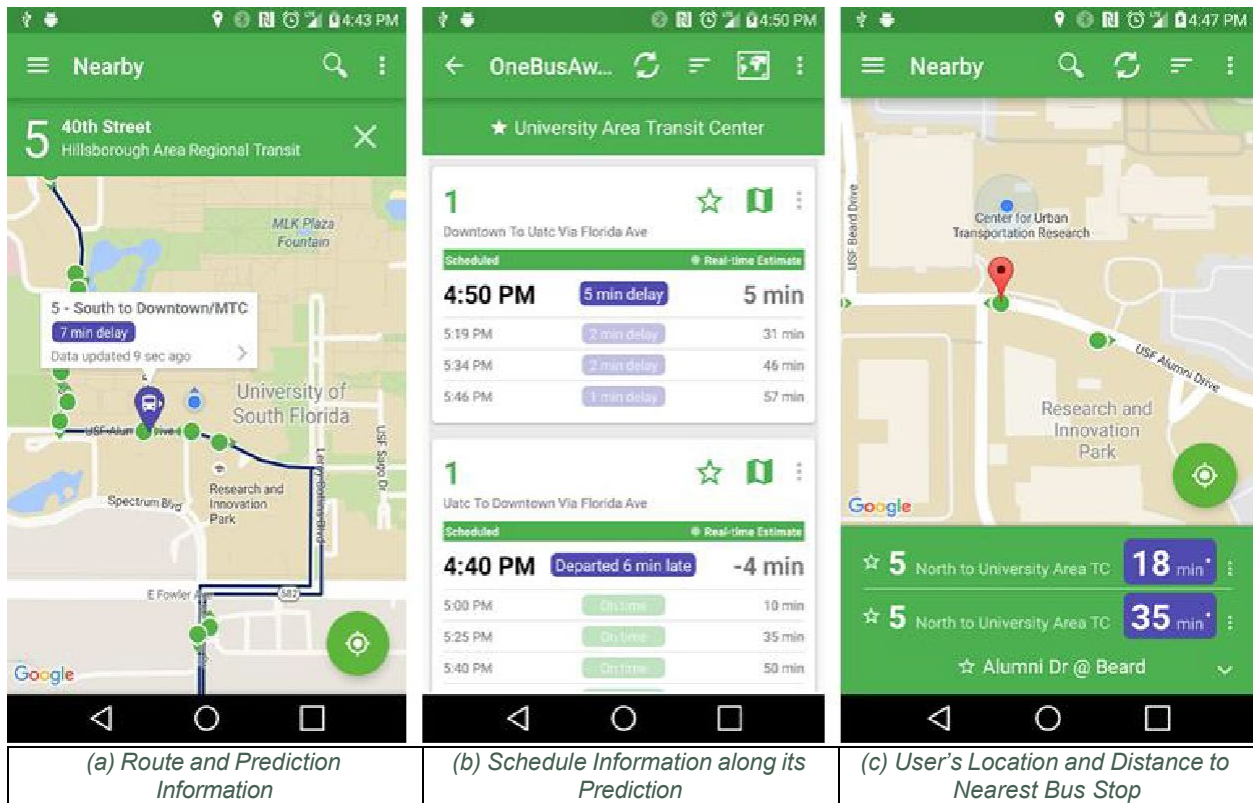
Figure 19. Demonstration of the Appearance of OBA Application.

The paper "Where Is My Bus? Impact of Mobile Real-Time Information on the Perceived and Actual Wait Time of Transit Riders" (Edison, 2011) examined the impact that real-time data provided by the application OneBusAway has on the perception of users' waiting times. A randomized survey system was used to collect data and test the following four hypotheses:

1. Bus riders perceive that they are waiting longer for a bus when compared to their actual waiting times.
2. Real-time bus arrival information reduces the perceived waiting time of the bus rider to bring it in line with the measured waiting time.
3. Real-time bus arrival information reduces the aggravation level experience by the bus rider.
4. Real-time bus arrival information reduces the actual waiting time of the bus rider.

Figure 16 shows the conclusions of the survey. The bar graph presents how users answered the survey conducted by mode of transportation and whether the implementation of OBA would improve their transit experience. The vertical axis represents the mode, and the horizontal axis represents the answer of each participant considering the five options available (presented in the legend). Since this project aims to implement OBA in a bus system operated in Mayagüez, Puerto Rico, the research team is interested in the results obtained from data collected from bus users. Figure 20 shows that 100% of the survey participants stated that for bus transit users, the implementation of OBA is an improvement in their experience, with 67% indicating that OBA would significantly improve and 33% slightly improve their transit

experience. The project team aims to see a similar situation with the implementation of OBA in Mayagüez.
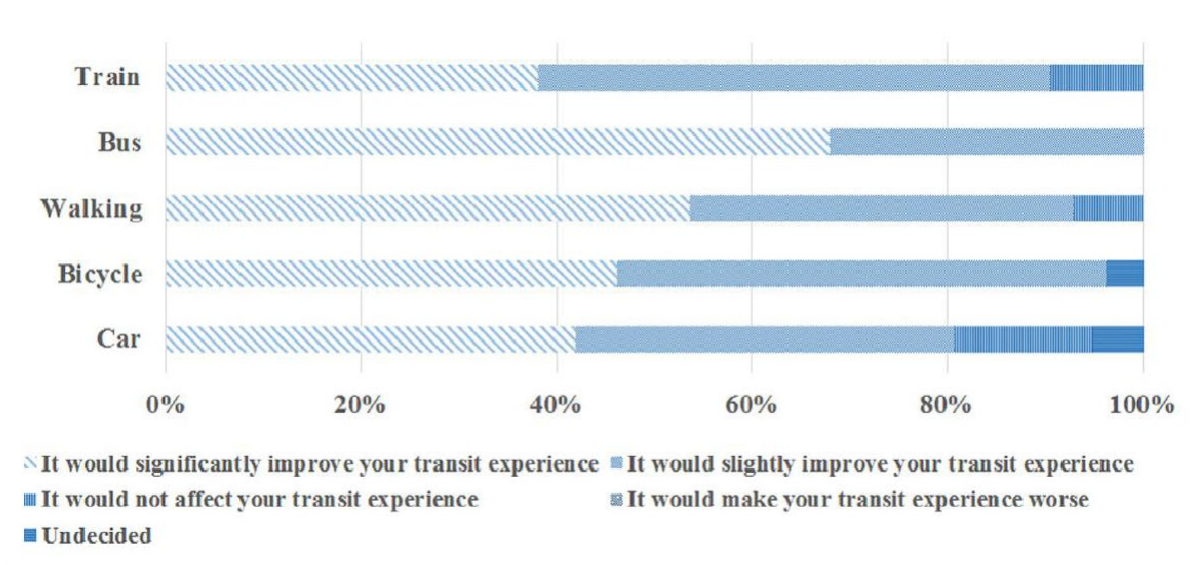

Figure 20. Findings of "Where is my Bus?" After Implementing OBA
Source: Edison 2011

2.3 Real-Time Transit Information and Ridership

Numerous mobile applications have made it possible for public transit passengers to find routes and determine the expected arrival times of buses in real-time. Research has been performed to study several aspects of this phenomenon. In 2009, a survey was conducted in Seattle to analyze the user experience with real-time information provided by implementing OneBusAway (OBA) in that city. The objective was to measure the information's effects on safety, time spent waiting, and overall satisfaction. In 2012, three years after developing the mobile application, another survey of current OBA users was conducted to compare the results with the 2009 study. Results showed significant positive shifts in satisfaction with transit, perceptions of safety, and ridership frequency due to the increased use of real-time arrival information (Gooze et al., 2013)

Brakewood et al. (2015) conducted research in New York City to identify the impact of real-time information on bus ridership. The study focused on the local bus service operated by New York City Transit (NYCT) and the implemented real-time bus information platform known as "Bus Time." The results revealed a median increase of 1.7% in weekday route-level ridership. Brakewood et al. (2014) also researched the bus riders in Tampa, Florida, to quantify the benefits of RTTI provided to bus riders. The results showed that the benefits associated with providing RTTI to passengers are related to waiting times at the bus stop:

- A nearly 2-minute decrease in "typical" waiting times for RTI users.
- Decreases in anxiety and frustration levels while waiting for the bus.
- Increases in satisfaction levels with the time spent waiting for the bus and how often the bus arrives at the stop on time.

2.4 OneBusAway (OBA) Platform

This project aims to implement OBA in a bus transit system, as it appears to improve user experience. OBA is a solution to the expensive implementation of RTPI third-party systems. OBA is an open-source platform that can provide real-time transit information to passengers (Ferris et al., 2009).

A suite of programs is required to implement OBA. This suite of programs consists of Traccar, Transit Clock, and OBA. The first two programs mentioned run in the background while OBA presents the information to the user.

Traccar is an open-source GPS tracking service. It offers a variety of GPS device ports to connect to the service. In addition, to tracking GPS devices, it also has a mobile app, "Traccar Client," which offers a simple way to test GPS tracking on a server with any intelligent device compatible with the application.

The Traccar software can be used as a cloud server and as a local server. To a GPS unit, the Traccar website provides a list of ports where Traccar expects specific devices. These devices are the GPS; the compatible devices are on a list on the Traccar website where each of the devices has a reference port to the Traccar service.

Once the GPS unit is obtained, Traccar shows instructions on how to connect the GPS unit to its servers. The user finds the Device Identifier and adds it as a GPS to the server. On the GPS settings, a Traccar user can reference the GPS to send data to the server address and the port.

According to Transit Clock they are the leading real-time bus arrival prediction software. Transit Clock is an open-source software that provides arrival predictions for transit systems. Currently, Transit Clock provides its services to various companies, including goEuropa in Poland, City Movil in Chile, OmniModal in Florida, and Cambridge Systematics in Washington. Transit Clock uses the bus location from the GPS and outputs predictions updates and then transmits it to OBA to be shown to the final users.

The benefits of implementing OBA in a transit system include reducing waiting times at the stop, reducing the perception of waiting time, planning trips more efficiently, and increasing the satisfaction of riders. (Watkins et al., 2020) A survey of OBA for Seattle-area bus riders showed increased overall satisfaction with public transit, increasing feelings of safety, and even a health benefit in terms of increased distance walked when using transit (Ferris et al., 2010). A Chicago study found that providing real-time transit data increased ridership by two percent (2%). Another study in New York found that the increase in ridership led to an additional $5 million dollars in yearly revenue (Canales, 2018). Thus, implementing OBA benefits not only the user but also the operator. The TIM system is free of charge, but the implementation of OBA can still be beneficial to the operator by providing information for the programing of maintenance and system operations and providing valuable data on the demand of the system.

Based on the registered benefits, OBA expands the coverage of the existing Android, iPhone, Windows Phone, and Windows PC apps for OneBusAway to new cities, including Tampa

and Atlanta (Barbeau et al. 2014). Some of the locations where OBA has been deployed are Washington, Oregon, San Diego, Argentina, and Canada.

One of the concerns with implementing this service is the implementation of GPS systems in a vehicle. There are documented cases where employees have expressed their concern with an invasion of privacy when employers try to implement GPS systems in their vehicles to offer a service that also provides real-time information (Kari et al., 2013). As a result, several courts have held that where an employer attaches a GPS tracking device to an employer-owned vehicle, an employee driving that vehicle is not allowed to state a claim for invasion of privacy when the employer tracks the whereabouts of the vehicle. When bus operators were interviewed on the subject, they expressed their fear that GPS data could be used to penalize them (Edison, 2013).

Implementing RTPI presents more advantages than disadvantages. The users improve their traveling experience. The operators improve the information available to make better decisions for their users. The general public also benefits from reduced congestion levels when more trips are made using a reliable and efficient transit system. Also, the cost that could be prohibitively high for budget-constrained agencies is substantially reduced with the implementation of an open- source platform such as OneBusAway. Therefore, RTPI is considered one of the best strategies to implement in transit systems.

3. Methodology

This section presents the methodology followed in conducting this research project, including integrating all the application components and the initial step of its implementation.

3.1 Methodology Overview and Tasks

The investigation follows the methodology shown in Figure 21. It has been divided into four main tasks developed in sequence.

Figure 21. Methodology of the investigation.

Task 1: Develop a knowledge base on the OBA.

The first task was to understand OBA. This understanding involved a literature review and research about how the RTPI application works and the steps that must be taken to implement it. To better understand how to implement the system, the project team met with partners at the University of South Florida (USF) who have successfully implemented OBA in other cities. The project team also met with OBA developers to obtain the necessary knowledge and skills to implement OBA.

Task 2: Meetings with transit managers and providers.

This task included presenting the OBA Platform to the UPRM Administration, the Mayagüez Municipality, and Sonnell Transit. The main reason for these meetings was to make presentations of the work intended, and request cooperation from these institutions since the UPRM operates the routes of the University, the Municipality operates the TIM urban routes, and Sonnell Transit operates the TIM rural routes. The Dean of Administration Office at UPRM served as a liaison between the NICR team at UPRM and the Mayor's Office. Therefore, the UPRM administration and the personnel of the Mayor's office established the connection to

handle the elaboration of a cooperative agreement following the recommendations provided by the NICR team. A Cooperative Agreement was signed with the Mayor of Mayagüez to formally establish the collaboration of all the parties involved in implementing OBA in Mayagüez. Also, authorization was obtained from the Administration Dean at UPRM to implement OBA in the university bus system.

According to the signed cooperative agreement, NICR will be in charge of the platform implementation activities for the urban and rural systems of the Municipality. The activities covered include the development of the necessary static data files, the programming for the operation of the tracking platform, and the training of the personnel designated by the Municipality to manage the tracking platform once it is implemented.

The Municipality will provide real-time location information for its buses from the urban and rural TIM systems by installing geolocation units (GPS) equipped with suitable SIM cards to transmit the location data required by the tracking platform. The Municipality will also provide information on the operation of its systems, including the routes and the stops. The Municipality will provide access to the urban and rural buses to conduct studies by the NICR research group. Also, the Municipality authorizes the NICR research group to use the information from the urban and rural TIM system and the real-time geolocation of buses to carry out further research in the future.

Task 3: Understanding the transit system.

As detailed in the introduction, this task entailed researching the TIM system characteristics and all the operational variables involved. This information includes a description of the activity system, the transportation system, and the flow pattern. In addition to the system's description, the understanding of the transit system involves the identification, geographical location, and mapping of the routes and stops. The geographical location is stored in a GTFS format file. GTFS is the acronym for General Transit Feed Specification, a compressed zip format file that stores and distributes information of a transit system. The mapping was done using GPS equipment and Cell Phone applications, like Geo- Tracker.

Task 4: Testing and Implementation of the OneBusAway platform.

This task is divided into two tasks as shown in Figure 21. This task included all the programming procedures to make the system operate and the tests performed to implement it. The tests had to be done in coordination with the system administrators and the operators of the routes. The procedures requiring programming code required to implement the system are shown in the next section.

3.2 Methodology of the Integration of all the System Application Components

The integration of the system application components followed the methodology is presented in Figure 22 generated by our research team based on the steps followed. This methodology for integrating the system application components includes all the programming procedures to make the system operational. The software utilized were: Traccar, for GPS
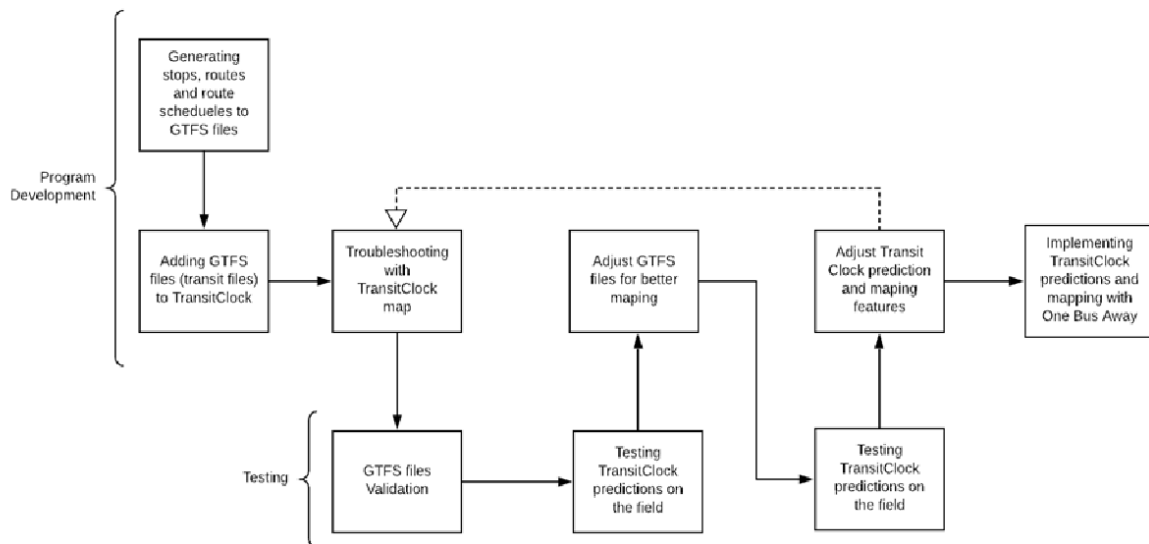
tracking; Transit Clock, for bus arrival time predictions; and OneBusAway, for visualization of the GPS location and arrival time of the bus at a desired location.

Traccar's main purpose is to load the GPS coordinates on the server. Traccar is the software that stores and shows the GPS bus locations that are transmitted to Transit Clock. Transit Clock uses the Traccar given GPS location and implements GTFS files. This first integration generates a map of all the routes in the Transit System. Using the bus location, the stops, and previously recorded trips, the Transit Clock estimates time arrival predictions for the next stop. Finally, OneBusAway collects the predictions and routes from Transit Clock and visualizes the information into a series of platforms, such as a web app and a mobile application.

The first step in developing the system application is the generation of static GTFS files of the transit system. The GTFS contains static information about the transit system. It is a bundle of files that describes the transit system containing information about stops, routes, schedules, and trips. The second step combines the static GTFS with the location data obtained

Figure 22. Flowchart of the methodology used to integrate the system application components.

from the GPS, called dynamic GTFS, and transmits it to Transit Clock. The third step involves a series of tests, validation, and adjustments of the GTFS and the programming code to have successful results before final implementation. Each of these steps is described in the following sections.

3.3 Initial Step for Implementation

This step included understanding the OBA platform, meeting with the relevant agencies, and gathering information on the system's routes.

Understanding OneBusAway (OBA)

The OBA application gets its information via a mobile phone that is connected to a server. The server is connected to the providers and the schedule data and real-time data that come from the agency that runs the bus service.

During the time allocated to understanding OBA, the project was dedicated to researching all procedures necessary to implement the platform. Literature reviews were performed to understand the inner workings of OBA. As mentioned before, the suite of programs needed to implement OBA includes Traccar, Transit Clock, and OBA itself. Traccar

receives the real-time information from the GPS and transmits it to the Transit Clock. The Transit Clock program uses that information along with GTFS files to make the predictions used for OBA. OBA receives the real-time data and predictions from Transit Clock, processes the data, and delivers it to the users' devices.

As part of this task, the UPRM research team coordinated meetings with USF to verify that the intricacies of implementing the open-source platform OBA in a new city were understood. There were virtual meetings with Dr. Sean Barbeau and his team from USF, who shared the OBA platform's know-how.

Meeting with Transit Managers and Providers

Meeting with the transit managers and providers was a crucial step in the implementation of OBA. The research team presented to the Administration Dean of UPRM the goals of the project. A similar meeting was also conducted with the representatives from the Major's Office of the Municipality of Mayagüez. These meetings were the beginning of the collaboration process.

As the implementation of OBA continued, additional meetings with the Mayor's office were necessary. These resulted in the signing of a Collaborative Agreement between the Mayagüez Mayor's Office officials and UPRM to implement OBA in the municipality.

In February 2021, the project team visited the TIM headquarters along with the agency's supervisor, Luis Feliciano. In this technical visit, the supervisor assisted the research team in verifying the bus stops' geolocation and the colloquial names for each stop. The colloquial names for the stops were utilized as a part of the implementation of OBA to make it simpler for local users, who are used to the system, to navigate the application.

Gathering Route Information

As mentioned in Task 3, General Transit Feed Specification (GTFS) is a compressed zip format file for distributing and transmitting information of a transit system. As shown in Figure 23, this compressed file is composed of various text files with information about the system's several characteristics, such as routes, stops, and schedule. The files included in the GTFS are agency.txt, calendar.txt, calendar_dates.txt, fare_attributes.txt, fare_rules.txt, frequencies.txt, routes.txt, shapes.txt, stop_times.txt, stops.txt, and trips.txt. Information of the system was gathered corresponding to the variables needed to build the General Transit Feed Specification file.
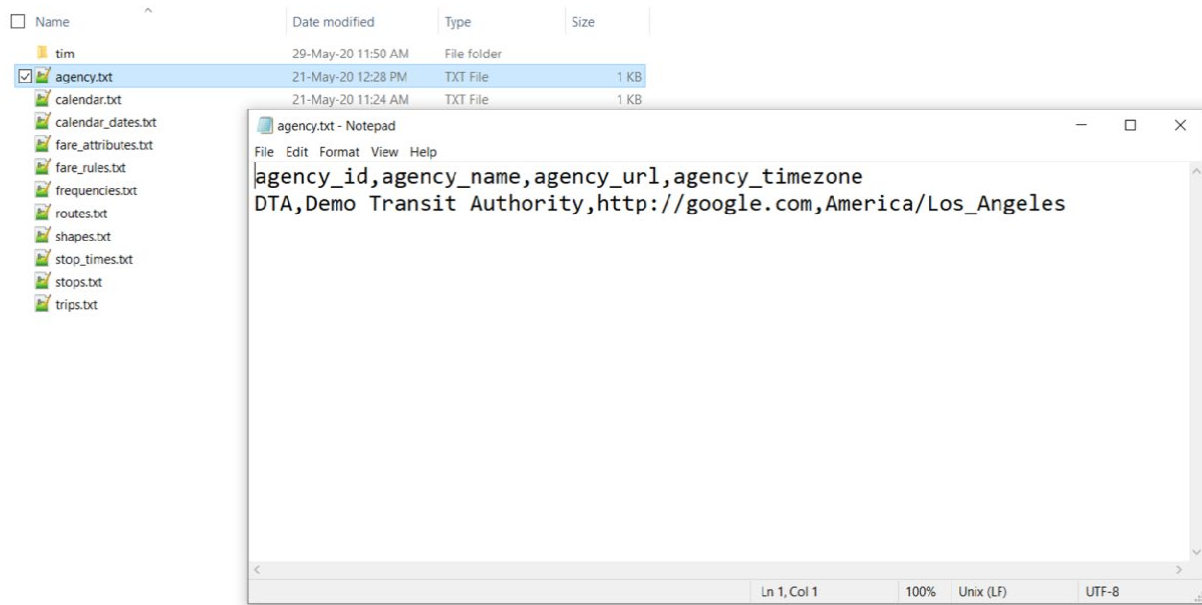
Figure 23. Text files that compound the GTFS compressed file.

The file **agency.txt** contains information about the name of the agency, the identification name (id), and the time zone of the location of the transit system. The file **calendar.txt** contains information about the start date and the end date that the system will be available, and the day the system is in service. The file **calendar_dates.txt** includes information on the dates that the system will not operate due to exceptions, such as holidays. The file **fare_attributes.txt** contains information about the different types of fares, the type of currency, and the payment method. The file **fare_rules.txt** includes information on the different types of fares applied to each route of the system. The file **frequencies.txt** contains information about the headway of the buses that operate in each route of the system and the period that this headway will be implemented. This file can be left empty if the system does not work with headway frequency and instead operates with schedules. The file **routes.txt** contains information about all the system's routes, including the id, the short name of the route, the long name of the route, and the description.

The file **shapes.txt** contains information about the spatial location of the routes, like the geographical coordinates of the points that belong to the line that defines the routes, in latitude and longitude format. The file **stop_times.txt** contains information about the schedule, such as the arrival and departure time of the buses to the stops in each trip. This file also has information about the sequence of the stops. The file **stops.txt** contains information about all the stops of the system, the name of the stop, and the geographical coordinates in latitude and longitude format. The file **trips.txt** includes information on the trips that have been scheduled, the route to which it belongs, the direction of the trip, and the shapefile to which it is associated.

The information needed to feed these files is obtained from the bus operators and a survey of the geographic location of the routes and stops. The survey was carried out with an application installed in a cell phone that tracks its location and pins specific points to be stored

in a text file that can be later used. The application used to make the survey is called Geo-Tracker, as seen in Figure 24.

The information gathered corresponds to the tracklog of the route that uses the buses when they are operating and the geographical location of the stops. This information is later processed in a Geographical Information System (GIS) software like QGIS to export to a shapefile format seen in a map or other GIS software.
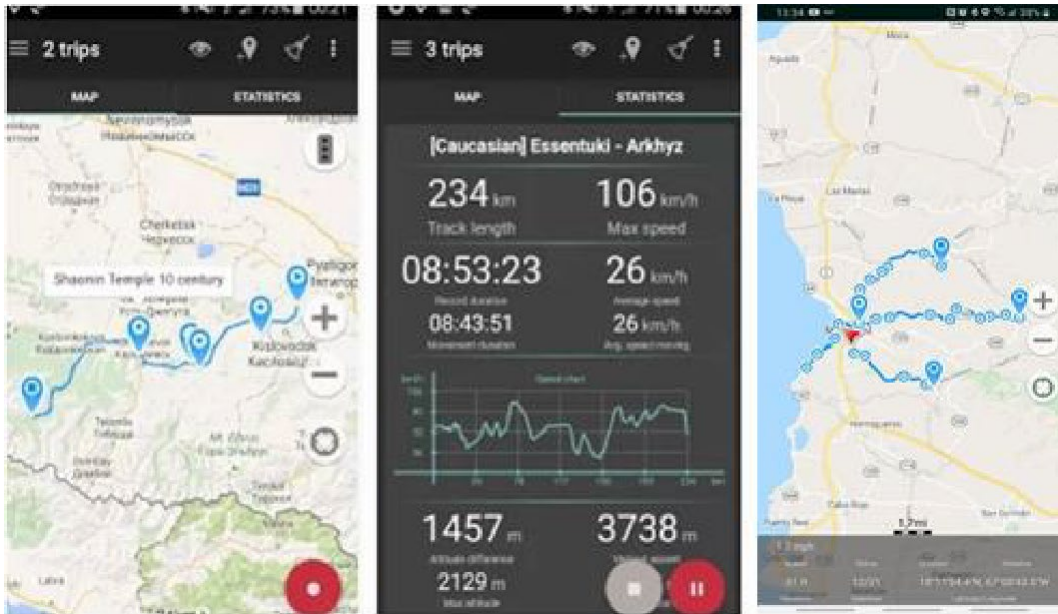
Figure 24. Geo-Tracking Software

The information collected is stored in two types of files, as shown in Figure 25. The information about the characteristics of the system is saved in an Excel file (*.xls). The information about the geographic location of the routes and the stops is saved in an Esri Shape file (*.shp). These files must be converted to a corrected text file that has a document structure that follows the Best Practices for GTFS. "Best Practices for GTFS are recommended practices for describing public transportation services in the General Transit Feed Specification (GTFS). These practices have been synthesized from the experience of the GTFS Best Practices working group members and application specific GTFS practice recommendations" (GTFS 2021). These best practices define a way to fill the text files of the GTFS, like the dataset publishing and general practices, which relate to the overall structure of the GTFS dataset.

Figure 25. Excel and Shape files of the information of the Transit System of Mayagüez.

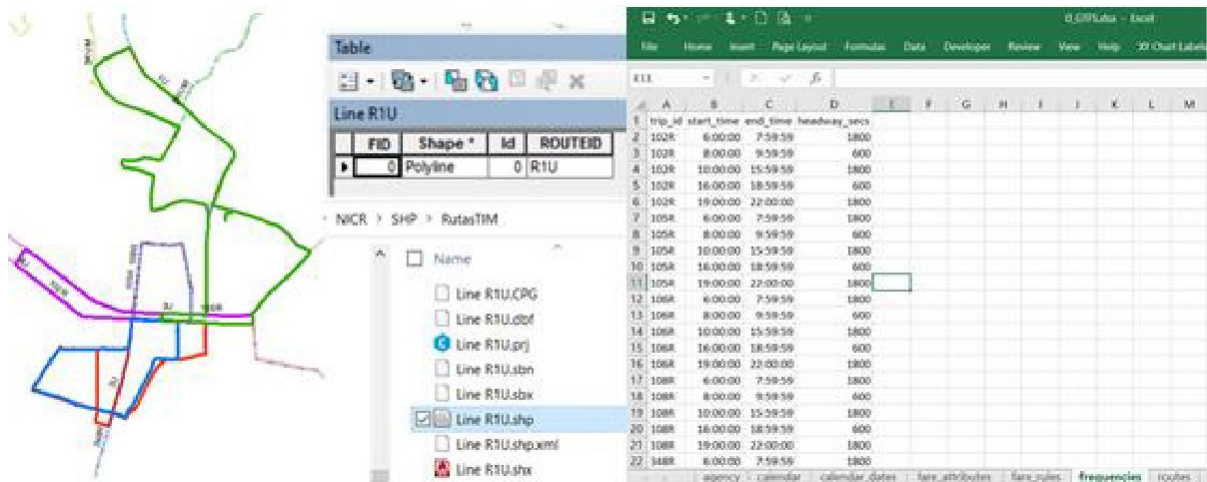The conversion of these files is done with a programmed routine made in the Knime Analytics Platform. According to Valdes et al. (2017), Knime is an open-source program that improves the data mining process effectively by using modular nodes. The nodes are pre-programmed to do a specific task. A particular advantage of this program is its graphical interfaces representing linear or cyclical processes, including processing, modeling, analysis, and data visualization.

As shown in Figure 26 and Figure 27, the routine processes the shape files corresponding to the lines of the routes and the geographical position of the stops and converts them to the corresponding text files.

The routine called **Shapes** that processes the shape files is a compound of 20 nodes: four nodes to locate and list the files, two nodes to make a loop to repeat the task for each shape file, one node to read the shape file, and the remaining nodes to process and structure the field as recommended by the Best Practices for GTFS.

The routine called **All Other** that processes the excel files is a compound of 20 nodes. Four nodes to locate and list the files, two nodes to make a loop to repeat the task for each tab of the excel file, one node to read the excel file, and the remaining nodes to process and structure the field as recommended by the Best Practices for GTFS.

Once all the text files are processed and compressed in a zip file, the GTFS must be checked. The program recommended by the GTFS Best Practices to check GTFS files is "transitfeed-1.2.16." Transitfeed is a Python software developed to test the structure of the GTFS files. This software validates the information saved in the GTFS files with the structure recommended by the GTFS Best Practices (GTFS, 2020). Figure 28 shows the report of Transitfeed for the GTFS file used in this investigation which was validated successfully.
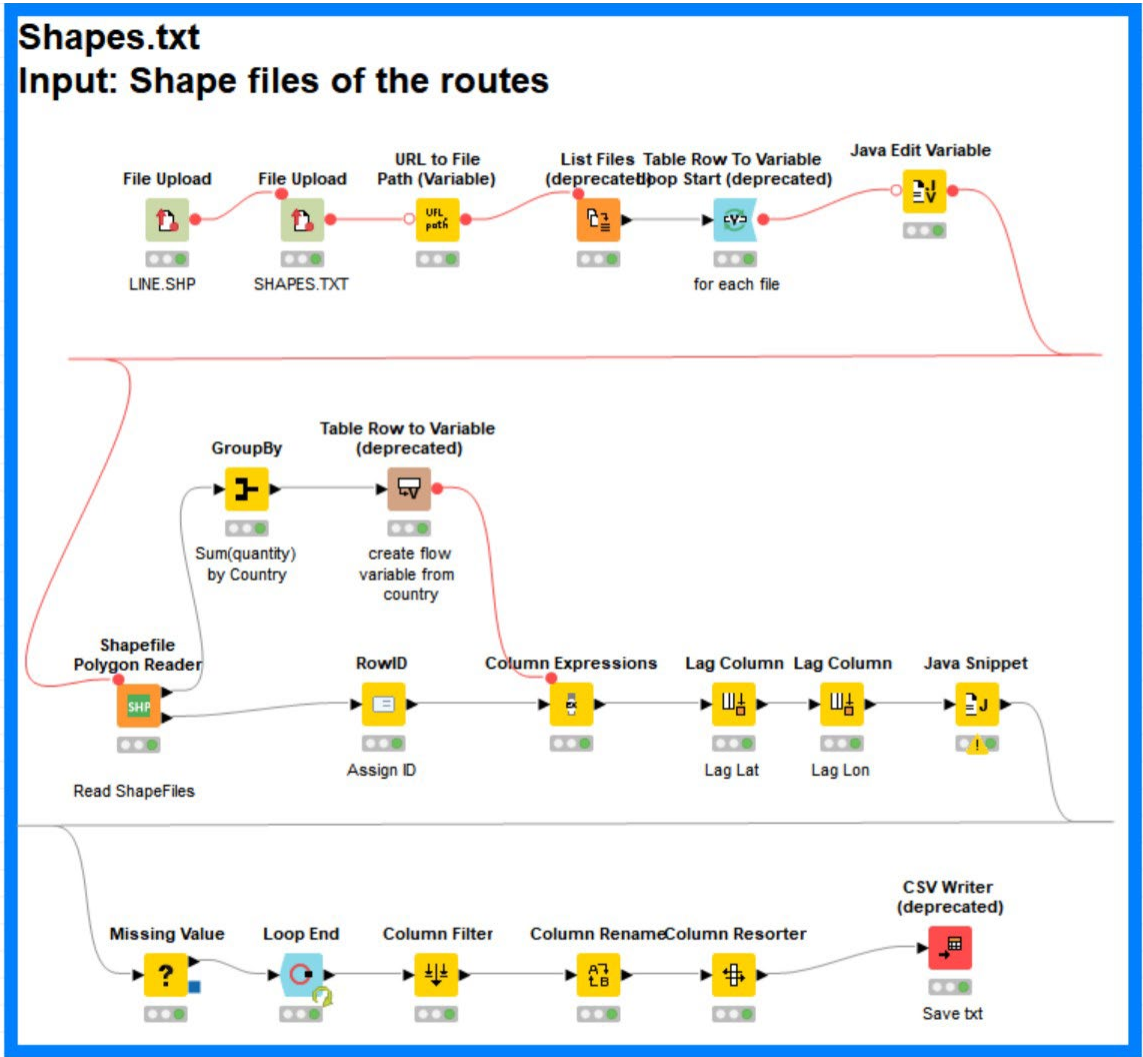
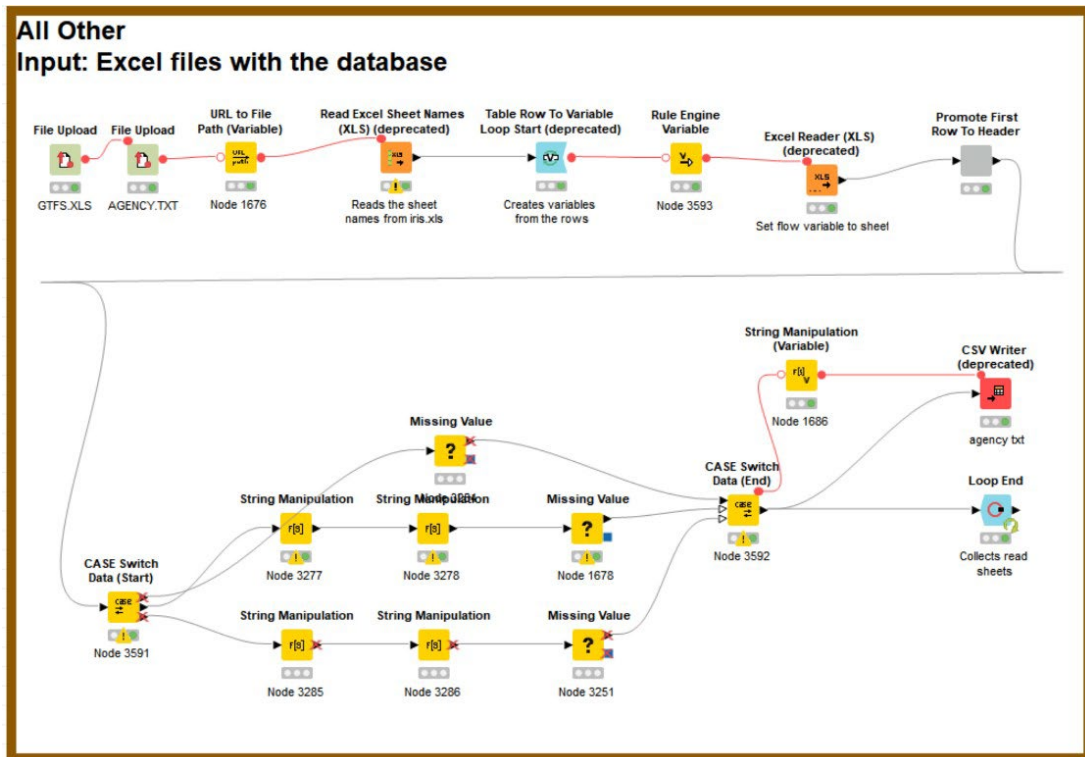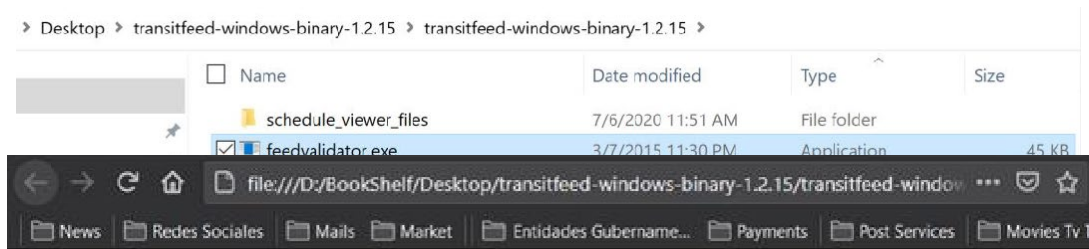**Figure 26. Shape routine used in Knime Analytics Platform.**

Figure 27. Routine used in Knime to process and convert the information to GTFS text files.

Figure 28. Validation of the GTFS by Transitfeed 1.2.15.

4. Analysis and Implementation

This section presents the steps taken to implement OBA in Mayaguez, which include the GPS connection to Traccar, verification of GTFS data and predictions of Transit Clock, and finally, testing OBA. This section also contains the data gathered on the activity and transportation system.

4.1 Implementation

As previously mentioned, the primary software programs are Traccar, Transit Clock, and One Bus Away. Traccar is used for GPS tracking. Transit Clock is used for bus arrival time predictions and OneBusAway to visualize the bus's GPS location and arrival time. Traccar's primary purpose is verifying and showing a GPS coordinate on the server. When a new GPS unit is implemented for testing purposes, it will be connected to Traccar. Transit Clock Traccars GPS data and implements GTFS files. This procedure generates a map of all the routes in the Transit System. Using the bus location, the stops on the routes, and previously recorded trips, the Transit Clock outputs time arrival predictions for the next stop. Finally, OneBusAway obtains the generated routes and stop predictions from Transit Clock and visualizes the data into and mobile application.

The initial development of these programs was developed on a local server. After running each service and adjusting it to the Mayagüez routes, the services were moved to a cloud server. Two servers are used in total. The first server hosts the Traccar and Transit Clock instance. The specification for the server is two CPU Intel Core, two GB memory, 60 GB SSD, and three Terabytes of data transfer. The second server hosts OneBusAway. This server processing load is shared with the first server. Although the IP address is different, both share processing power and memory. Its specification includes two CPU Intel Core, two GB memory, 25 SSD memory, and three Terabytes of data transfer.

Traccar

Traccar is the platform utilized to connect the GPS to the server and relay the geo-location of the vehicle to OBA. This process can be achieved through a dedicated GPS device or a smart device compatible with the Traccar application. For the research, a cloud server has been used. Initial testing and verification of the Traccar connection was performed utilizing the smartphone of a research team member.

Transit Clock

After running a Docker Instance of Transit Clock on a local server and several tests, the research team found that there was an overlap on the routes. This situation was due to an error in the GTFS files. In addition, after each test drive, the Transit Clock instance was further adjusted to suit the Mayagüez Transit System.

Adjustments made to Transit Clock during tests

Transit Clock auto assigned a vehicle to a route. This process was performed due to the use of Traccar. At that moment, the test was performed using a mobile device GPS. Traccar gets GPS location; however, it was theorized that it could not reference a vehicle to a specific route. The GPS is first added in the Traccar. Afterward, Transit Clock gets the vehicle coordinates and

decides which of the nearest routes the vehicle will be assigned to. The routes along the roads of Mayagüez sometimes have long distances between bus stops, and some areas have little reception for the GPS. For this reason, the distance required to detect the route to which each vehicle is assigned was modified until the distance that best worked with the Transit system was found.

When generating the predictive analysis in Transit Clock, the system couldn't register the bus stops in the TIM. The set value by the system had to be modified because the length between bus stops are too far from each other. This modified configuration is a crucial specification that needs to be adjusted for Transit Clock to be able to read and generate the GTFS bundle and make the predictions for arrival times.

For the tests that were done, the Transit Clock variable "late seconds and early seconds", which is related to the vehicle arrival time at the stop, was modified. This variable stated if the vehicle was late or early for a given time. In some cases, the arrival time given would change from predicted analysis to the GTFS given time, depending on the number of late seconds selected.

During the tests, the vehicle arrival time predictions were usually accurate. When given a wrong estimate, it was due to a GPS error, bad signal, or bad connectivity from GPS to server. One of the details observed in the tests was that these errors occurred on the same routes and usually in the surroundings of specific locations.

The Mayagüez Transit System has both rural and urban areas. For such reasons, if the software was adjusted to rural areas, then the urban areas were affected. The rural areas have longer distances between bus stops when compared to the urban areas. In some instances, the closer the bus was to the stop, the more accurate the arrival estimates, but the initial first predictions were sometimes not accurate.

Transit Clock Errors during Tests

During the tests, the first error seen was a route overlapping. When Transit Clock was running, its stops formed "overlapped routes" between them. Bus stops formed straight lines between them when there should not be any line. When the software is running, the routes follow the geographical route on a map. These overlapping routes showed straight lines, meaning that they did not follow the correct geographical routes that were in place. Interestingly, the program runs without showing any errors while running. The error from the GTFS was indicated in the log output file. The program could match a bus to a route and give predictions, but the lines would still be present.

When running other public test GTFS files from other companies, the error was present as well. Even the GTFS of companies that used OneBusAway and Transit Clock showed these overlapping stops. It was speculated that it was an internal error of the Transit Clock GTFS visualizer. Later, it was determined that it was an error due to how the GTFS stops were organized.

During the first instances of Transit Clock running tests, there were many adjustments made to the auto assigning variable that dictates to which route the bus was going to be assigned. At some moments, the vehicle got assigned to several routes but not the route the test was going to be performed. Additionally, in some cases, the vehicle disconnected randomly from

the assigned route, and for the rest of the trip, it did not reconnect to the route. This was one of the most frequent errors, and the most troublesome, because the rest of the route did not provide information for the test. Consequently, it did not show any results; the only observation that could be collected was how the GPS behaved.

Testing Different GPS Devices and Selecting the Best Choice

To find a suitable device for the project, the team researched the different GPS units that Traccar suggested. The most extensive selection of GPS devices from Traccar was Teltonika; therefore, devices were selected from this company to avoid compatibility errors. Afterward, the team established some critical features needed for the GPS to be suitable for the project. Some of those features were the easiness of GPS installation and its location. Due to the characteristics of the transit system of Mayagüez, some of the vehicles already had some ports in use.

Additionally, a GPS that was easy to remove was also needed; this was a feature that was asked by the bus operators citing as a reason when a vehicle needed a service (i.e., maintenance, repair). As such, they needed to quickly remove the GPS to install it in another vehicle. Another request was about the possible use of a tablet. The specifications for the tablet were mainly software- oriented. The team had to verify its OS compatibility with both the Traccar and OneBusAway applications. Beforehand, the team used the emulators from Android Studio to confirm that both applications could be used on the tablet. With these specifications in mind, the following GPS devices were chosen GPS model Fmt 100, GPS model Fmb3000, and Samsung Tab A.

After setting up the GPS devices and connecting them to SIM cards, the team tested each device. A series of tests were made, including verifying a GPS could be seen on Traccar and making sure the software was working and capable of having various GPS devices simultaneously. Afterward, the team used each GPS device on a vehicle to have test runs on the routes of the transit system. In these tests, we considered two key observations. First, how the GPS signal error range fluctuated and observing in which regions did the GPS jump location position through the routes instead of following a continued route. As an example, some routes are on a mountainous area which could cause some latency in the signal reception for the GPS. This affects both the signal error range indicator and GPS location update.

FMT 100 vs. FMB 3000

The FMT 100 GPS was chosen due to its easy installation. The device is installed in the vehicle's battery, and it takes approximately less than two minutes to install. Removing the device is also quick and easy, thus making the unit a suitable GPS. Meanwhile, the FMB 3000 is installed in the On-Board Diagnostics (OBD) port of the vehicle. Most modern vehicles have this port as it is usually used for vehicle evaluations. Its installation is as easy as installing the FMT 100 since it connects it to a port like a USB device.

The difference between these two units is their performance. Although the FMT 100 was perfect in urban areas during the initial tests, it was not consistent in rural surroundings. When transitioning from rural areas to urban areas, the GPS error radius caused the GPS to send the wrong coordinates to the GPS. The FMB 3000 did not have this problem; its error radius was mainly the same throughout the tests. The biggest concern for the FMB 3000 was the

OBD2 port since not every vehicle has this port. In addition, some of the vehicles in the Mayagüez transit system already had this specific port in use for other purposes. Their problems with the GPS lay in how consistent it was. During the tests made when the GPS was successfully sending data, it had a good signal, a small error radius, and sent coordinates without fail; however, it was periodically disconnected. This observation was a problem because the software must match the GPS to a route; it is not pre-selected. In other words, if the GPS disconnects periodically, it will also disconnect to the route and, as a result, it will not give predictions.

Samsung Tab A

In contrast to the previously mentioned GPS units, the Samsung Tab A only needs the installation of the "Traccar Client" app and is quickly set up with the server. In the installation, the Samsung Tab A is more straightforward than the previous devices since it does not need a physical connection (i.e., to a battery or a port). In addition, it can easily be exchanged between vehicles. The additional installation of the tablet is the mount for the vehicle. The installation was solved by finding a support with screws, so it was fixed in the vehicle.

A test was made to evaluate the tablet with the previously mentioned GPS devices. It was found that the tablet was more consistent in sending accurate locations and had a lower error radius. The transition from urban areas to rural areas with the tablet was almost flawless. With minimal error range, the tablet consistently sent data. As part of the tests, areas that historically presented problems with the GPS signal were considered; therefore, errors were expected in these areas. Yet, the tablet overcame expectations and was able to send data in the error-prone observed regions.

After all observations and comparisons were made, the team opted for the Samsung Tab A that outperformed the other units. Additionally, it fulfills the installation requirements for easy removal and transfers from the vehicles.

Pilot Test

On February 6th, 2021, a test was done with the FMT100, FMB3000, Samsung Tab A, and a mobile phone. The test consisted of all the units passing on a route and evaluated how the different GPS units performed. All the GPS units were used simultaneously. During the test, the FMT100 and the FMB3000 encountered connection problems and GPS errors, causing them to send incorrect locations. In contrast, the Samsung Tab A passed through a route with rural and urban areas and performed well. The tablet showed impressive performance in areas where it was observed to cause bad signals continuously. It gave a small error radius that was consistent and precise with location updates in real-time.

After the test ended the following Monday, the tablet was installed on a Mayagüez transit system vehicle that travels along the highway PR-106, which serves both rural and urban areas. After daily observations, the tablet was connected 96% of the time; it estimated accurate daily locations and presented minimal error radii (around 5 meters). The GPS unit had consistent connectivity in Traccar and precise predictions in Transit Clock, showing that the tablet had an excellent performance for the project.

OneBusAway is the successful deployment of Traccar and Transit Clock. Unifying the GPS location of Traccar and the predictions of Transit Clock, OneBusAway can be successfully used by users. The primary feature of OneBusAway is user interaction. Contrary to the other services, OneBusAway strives to provide information to the user optimally.

4.1 Gathered Information on the Activity and the Transportation System

Information of both the Activity and Transportation System of TIM was gathered and stored in databases as presented in the following sections.

Database on the Activity System

As mentioned in the literature review, the activity system is defined by the area of influence surrounding the stops along each route. The area of influence is defined as the halfway point between one stop and the next and 500 meters outward from the stop. For this research project, this was further defined with the use of QGIS. An example is presented in Figure 29. All the structures that are inside the area of interest were selected utilizing the same software. Afterward, all the structures were cataloged according to the variables presented in Table 4 using land-based classification standards, ITE Trip Generation Tables, Google Earth, Google Maps, and general knowledge of the city. These variables were cataloged in QGIS in an attribute table where each structure has the corresponding variables attached to it in the file.
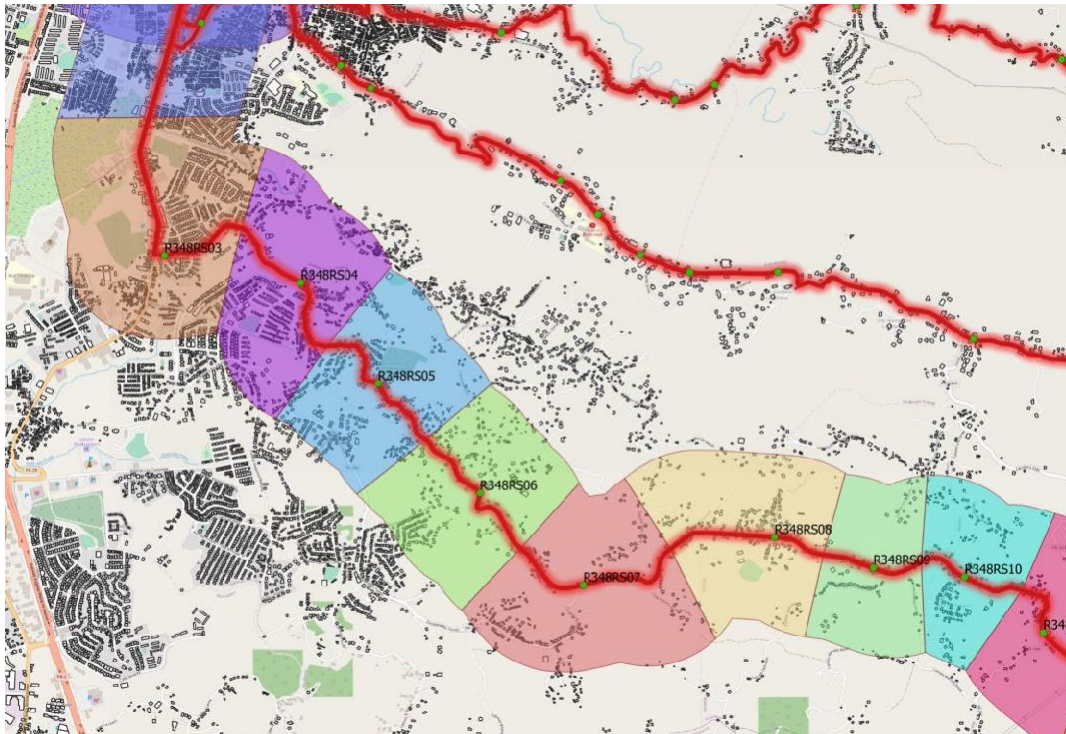

Figure 29. Areas surrounding the stops
Source: QGIS 2021

The total daily trip generation for all the activity areas was calculated using the variables presented previously. To do this, the classification of all the structures utilizing the ITE Trip Generation Tables was necessary. The *daily rate per unit* (DRPU) was determined using the ITE classification. The areas of all the structures were determined using QGIS. Multiplying the area and the DRPU resulted in the daily trips for any individual structure; these values were then added for each bus stop area. The data of the activity system was extrapolated to define and later analyze the impacts of OBA implementation.

The purpose of calculating the trip generation information is to determine the potential demand for travel in the TIM's area of influence. In phase 2 of this project, the data corresponding to the demand of each of the transportation modes will be verified to generate strategies that reduce the use of private vehicles and increase the demand for public transport.

In addition to the variables shown in Table 5, a set of variables was explored to identify any correlation between these variables and the transportation system. These variables were the demographic and socioeconomic factors, such as population, sex, race, per capita income, and poverty status. The primary sources used to obtain such data were the United States Census Bureau (USCB) and the American Community Survey (ACS) 2019.

The data found in the USCB contains an identification number called GEOID, which is associated with the geographical census block group with the same identification number. The variables obtained were matched using the GEOID code of the census block group. These variables are also presented in Table 5.

<p style="text-align: center;">**Table 5. Activities System and Socio-Economic Variables**</p>

Variable	Description	Variable	Description
STOP	Stop	B19013_001E	Med Household Income
LBCSA	Land-based classification standards activities	B01001_001E	Population
LUCT	Land use code type	B01001_002E	Male
LUCTD	Land use code type description	B01001_026E	Female
LUCD	Land use code description	B01002_001E	Median Age
LUD	Land use description	B02001_002E	White
A	Area	B02001_003E	Black or African American
NF	Number of floors	B02001_004E	American Indian and Alaska Native
DU	Dwelling units	B02001_005E	Asian
ODU	Occupied dwelling units	B02001_006E	Native Hawaiian and Other Pacific Islander
B	Beds	B02001_007E	Other Race
R	Rooms	B11012_001E	Household
DRPU	Daily rate per unit	B14007_002E	Enrolled in School
TA	Total am	B14007_019E	Not Enrolled in School
IA	In am	B19083_001E	GINI Index
OA	Out am	B19113_001E	Median Family Income
TP	Total pm	B19301_001E	Per Capita Income
IP	In pm	B25044_001E	Teneru Vehicle
OP	Out pm	B11006_001E	Presence 60 Years And Over
DR	Daily rate	B23024_001E	Poverty Status
OBS	Observation	B23024_002E	Income Below Poverty Level
PO	Population	B28002_005E	Cellular Data Plan
IN	Income	B28002_013E	No Internet Access

Database on the Transportation System.

The data transmitted by the GPS and received in Traccar Server could be downloaded for real- time analysis and stored for future research. It was necessary to make a request to Traccar Server through the web address to perform this task. This request must have the credentials of authentication for logging into the server. A workflow was developed in Knime Analytics, and it is shown in Figure 30. The workflow makes requests to Traccar, asking for information stored in the servers, like the geographical location of the buses in latitude and longitude format, the date and time of the geographical position, and the ID of the buses associated with the location. The information obtained is saved in a text format and can be used to make a performance analysis of the transit system.
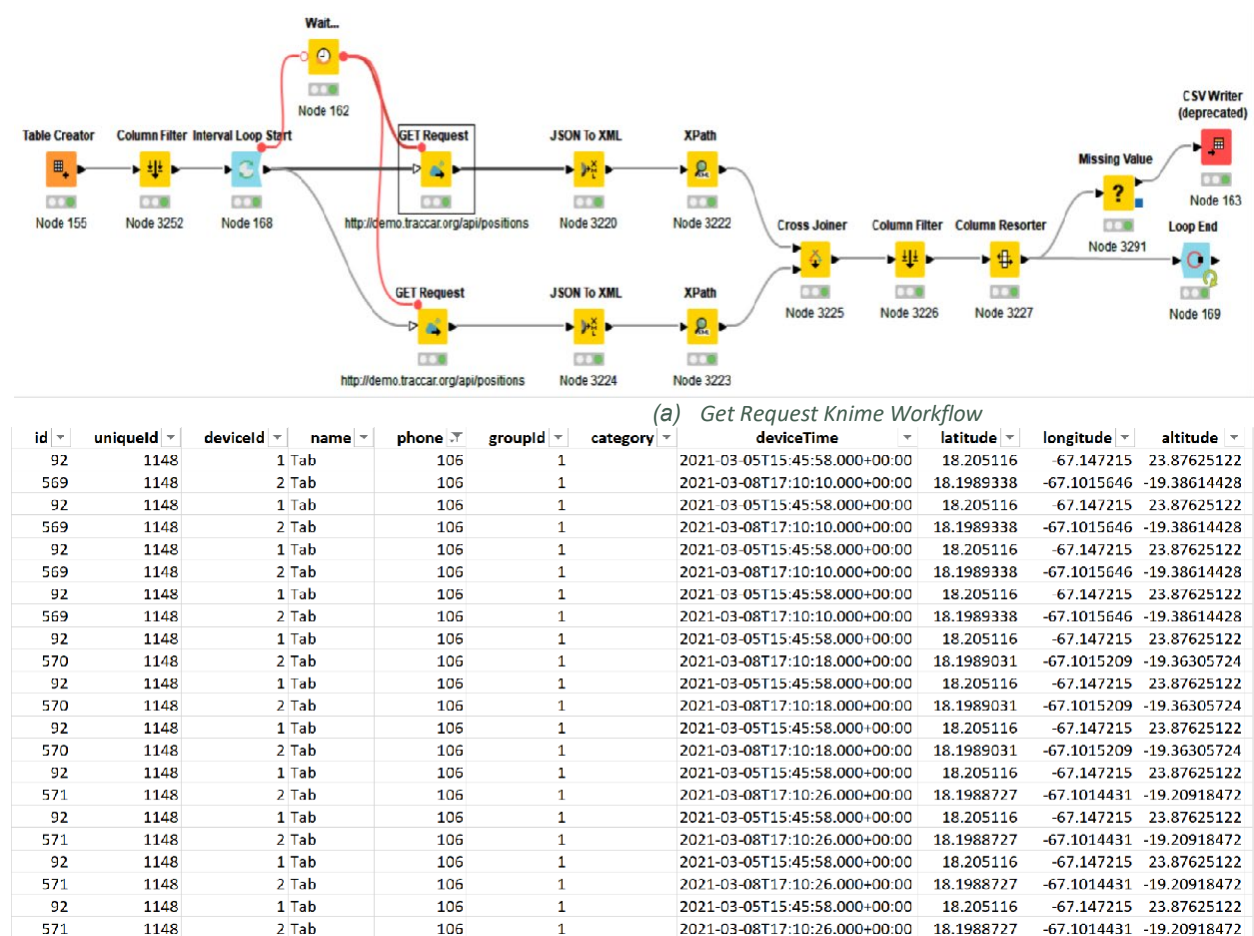

(a) Get Request Knime Workflow

id	uniqueId	deviceId	name	phone	groupId	category	deviceTime	latitude	longitude	altitude
92	1148	1	Tab	106	1		2021-03-05T15:45:58.000+00:00	18.205116	-67.147215	23.87625122
569	1148	2	Tab	106	1		2021-03-08T17:10:10.000+00:00	18.1989338	-67.1015646	-19.38614428
92	1148	1	Tab	106	1		2021-03-05T15:45:58.000+00:00	18.205116	-67.147215	23.87625122
569	1148	2	Tab	106	1		2021-03-08T17:10:10.000+00:00	18.1989338	-67.1015646	-19.38614428
92	1148	1	Tab	106	1		2021-03-05T15:45:58.000+00:00	18.205116	-67.147215	23.87625122
569	1148	2	Tab	106	1		2021-03-08T17:10:10.000+00:00	18.1989338	-67.1015646	-19.38614428
92	1148	1	Tab	106	1		2021-03-05T15:45:58.000+00:00	18.205116	67.147215	23.87625122
569	1148	2	Tab	106	1		2021-03-08T17:10:10.000+00:00	18.1989338	-67.1015646	-19.38614428
92	1148	1	Tab	106	1		2021-03-05T15:45:58.000+00:00	18.205116	-67.147215	23.87625122
570	1148	2	Tab	106	1		2021-03-08T17:10:18.000+00:00	18.1989031	-67.1015209	-19.36305724
92	1148	1	Tab	106	1		2021-03-05T15:45:58.000+00:00	18.205116	-67.147215	23.87625122
570	1148	2	Tab	106	1		2021-03-08T17:10:18.000+00:00	18.1989031	-67.1015209	-19.36305724
92	1148	1	Tab	106	1		2021-03-05T15:45:58.000+00:00	18.205116	-67.147215	23.87625122
570	1148	2	Tab	106	1		2021-03-08T17:10:18.000+00:00	18.1989031	-67.1015209	-19.36305724
92	1148	1	Tab	106	1		2021-03-05T15:45:58.000+00:00	18.205116	-67.147215	23.87625122
571	1148	2	Tab	106	1		2021-03-08T17:10:26.000+00:00	18.1988727	-67.1014431	-19.20918472
92	1148	1	Tab	106	1		2021-03-05T15:45:58.000+00:00	18.205116	-67.147215	23.87625122
571	1148	2	Tab	106	1		2021-03-08T17:10:26.000+00:00	18.1988727	-67.1014431	-19.20918472
92	1148	1	Tab	106	1		2021-03-05T15:45:58.000+00:00	18.205116	-67.147215	23.87625122
571	1148	2	Tab	106	1		2021-03-08T17:10:26.000+00:00	18.1988727	-67.1014431	-19.20918472
92	1148	1	Tab	106	1		2021-03-05T15:45:58.000+00:00	18.205116	-67.147215	23.87625122
571	1148	2	Tab	106	1		2021-03-08T17:10:26.000+00:00	18.1988727	-67.1014431	-19.20918472

Figure 30. Knime Workflow and Data Downloaded.
Source: Knime 2021

5. System Operational and Results

This section describes the OneBusAway (OBA) implementation in Mayagüez, including planning and preparation steps, the tests performed, and the deployment.

5.1 Preparations for Implementation

The initial steps towards implementing OBA were establishing the required systems for implementing a tracking system, a prediction system, and a visual system. When all these programs are running, OBA also functions. If one of the other two programs begins showing any problems, then OBA does not run correctly. Among the three programs in use, essential data exchanged are GTFS data and GPS data. Both inputs are the functions for Traccar, Transit Clock, and OneBusAway.

The initial step to prepare for the implementation is to obtain the vehicle location and send that data to a server. The program in use as a tracking system is Traccar. Traccar is an open-source project on GitHub which generates a web application that allows users to use a mobile application or an IP address and send the device's coordinates to the designated server. In short, Traccar is a web application that visually shows the current location of GPS devices and their last known location. The initial testing method for Traccar was using a mobile device and installing the Traccar mobile application. Afterward, the IP address and port of such a device are selected, and the device's interval is changed to one second. Once these steps are completed, the device is shown in Traccar.

A series of test runs were performed to verify that the system was working. A vehicle with a mobile device connected to Traccar traveled the public transit routes of Mayagüez. In addition, a pilot test was performed. In this test, the team deployed a series of vehicles to travel along the different routes of the transit system. In this test, it was observed that the Samsung Tab A exceeded the performance of dedicated GPS device units. Not only was the performance and GPS consistency tested, but also the GPS ranges of error. Traccar offers visual feedback when the GPS is last connected and when the GPS has a low signal and has an extensive error range for its coordinates. Furthermore, we found that the spots where the GPS has low signal repeated in the tests. In other words, the places where the GPS had a low signal could be identified beforehand. This issue was experienced mainly in rural areas. In urban areas, the GPS errors were minimal.

Once the tracking system was implemented and tested, the next software needed was Transit Clock. Transit Clock is also an open-source application hosted on GitHub. The function of Transit Clock is to use GTFS information and GPS vehicle location to predict the arrival time of the vehicle at the next stop. The Transit Clock primary input is a GTFS of all the routes of the Transit System; this bundle of files includes the days of service of the transit system, the arrival time of each stop of the system, the name of each route, name of each stop, and the shape of the respective routes. Furthermore, a series of GTFS were made. One after another, a series of improvements were consistently made and tested. Each bus in the Mayagüez Transit System initiates its daily operation at an established time, leaving the depot early in the morning. Near

noon, there is a change of drivers. The vehicle is expected to arrive at the depot at an established time at the end of the day.

At the beginning of the development of the GTFS, there was no arrival time per stop. That feature for the transit system was implemented and generated while developing the GTFS. The arrival time for each stop was determined considering the vehicle speed, the distance between stops, and the pick-up/drop-off time per stop. After generating the time per stop and routes, the GTFS was tested using a GTFS verifier. The function of this program was to verify that the time at each stop did not change and was consistent. In addition, it confirmed typos within the GTFS and the references from a stop to the respective route or routes.

During the testing of the GTFS, it was found that the Mayagüez Transit System routes are continuous. In other words, there is no terminal stop time at the end of the route. Each bus driver arrives at the final stop of a route and then continues back to the initial terminal. Thus, the last stop at the end of the route is the beginning of the route going back. This situation presented a problem. When implementing one route and representing it as a continuous route, the visual representation in Transit Clock generates straight lines which overlapped the route and passed over streets jumping between stops. Therefore, numerous evaluations and improvements were conducted using previous GTFS. Also, GTFS from other transit systems with a public GTFS were studied. Some of these deployed GTFS also presented the error that was seen on Transit Clock. At first, it seemed like a visual misrepresentation of the data, which was deemed an error in the Transit Clock visualization. However, that was quickly proven wrong when trying to connect Transit Clock to the OneBusAway.

After various errors when deploying OneBusAway referring to continuous routes in the GTFS, and after consulting with the University of South Florida, it was found that the problem was the continuous routes. The routes in place for the Mayagüez transit system were then remade to solve this problem. The continuous routes were changed into two parallel lines, each representing one direction of flow for the route. This new representation solved the glitch lines over the GTFS routes. In addition, further adjustments to the Transit Clock and One Bus Away configurations have been made to have more accurate arrival time predictions.

Another particularity found in the Mayagüez transit system was that the Transit Clock required adjusting the stop-by-stop length. In some instances, the GTFS was referenced as faulty due to stops being either too close or too far apart. This observation detected by running the Transit Clock was found in rural areas where the stops were further apart than in the urban areas. Also, in urban areas, some stops were deemed too close. After adjusting the Transit Clock as a result of the test runs, the predictions given by the Transit Clock were accurate.

After deploying a GPS connected to Traccar and referencing the GPS location to Transit Clock, the software began the next stop predictions. It was observed that in most cases, the forecast was on point by less than a minute. In other words, once the arrival prediction was given, a range of errors of one minute was present so that the vehicle would arrive at a designated stop in less than a minute. Additionally, the prediction also showed that the vehicle arrived earlier than expected in some instances. This arrival was labeled "early" due to the vehicle being more than one minute earlier than the predicted state. These variables change as the vehicle gets closer to the stop. The further apart the stops, in the rural areas, the less

precise the prediction is. But the closer the stop or the closer the vehicle to the stop, the more accurate it is.

Another test made to verify the performance of both Traccar and Transit Clock was deploying various GPS devices in the Mayagüez Transit System and corroborating both the frequency and precision of the prediction. In addition to the pilot test, this test evaluated how the GPS performance was seen throughout the route. As stated before, the faulty GPS spots are repetitive. After identifying the locations prone to affect the GPS signal, the rest of the route was evaluated. The GPS coordinates were accurate and presented good prediction values from Transit Clock. To assess the GPS devices, Traccar offers an optional interface that allows the user to view all the GPS devices connected simultaneously and determine the last time the GPS coordinates were updated. This feature is valuable due to the GPS errors; in some instances, the lack of Internet connection meant that the GPS could not send data. As a result, the last updated time would be updated in Traccar. In this scenario, Traccar is the most helpful program used to make this observation quickly. Aside from this, Transit Clock offers better visual information about the vehicle's location with respect to the stop and the arrival per stop. These scenarios occurred in the tests and became important observations for future references.

In addition to the pilot and test runs to verify the performance of both Traccar and Transit Clock, it was evaluated how optimal is the human interaction with both software. For example, one obstacle is the need for operator intervention for troubleshooting the Traccar service, Transit Clock service, and Traccar mobile application. During the tests performed to evaluate the stability of the connection between Traccar and Transit Clock, intermittent disconnection and reconnection of vehicles were noted. In some cases, the vehicles were reconnected without problem in a few minutes without the operator's intervention; yet in other instances, the vehicle did not reconnect. In periods where there was no testing performed for the vehicle GPS or the device was left "running" to evaluate if it would reconnect, the operator intervention was needed to re-establish the connection. Although the solution to the connection issue is easy to solve, it still requires human intervention. The answer to re-establish connection consists of opening the Traccar application of the faulty GPS unit and then subsequently disable and then enable the server connection with the application. Afterward, the GPS location should be seen on the Traccar web app. This simple procedure is the only human intervention needed in the Traccar service. In Transit Clock, aside from monitoring the predictions and adjusting the evaluated parameters for the prediction, little to no human intervention is needed.

Once Traccar and Transit Clock were deployed and functioning, the two programs were tested with OneBusAway. The initial result when implementing the three programs was that the GTFS needed to be fixed. As indicated before, when unifying the three programs, the OBA deployment provided an output specifying the need to solve the problem of GTFS looped routes. After solving the error and running OBA on a mobile device, the successful visualization of the routes and the vehicle was displayed on the screen. The importance of the deployment of OBA and running the three programs simultaneously is that OBA requires both vehicle locations from Traccar and a GTFS output that Transit Clock returns. As a result, both programs need to perform flawlessly for an OneBusAway instance to run. The testing made in OBA referenced

how the platform indexes the location of a vehicle and what happens if a vehicle disconnects while being on a route. In the initial evaluation of OBA, it was observed that it took reference directly from the GTFS arrival time. Therefore, in the case that a vehicle was not present on the map with real-time feed, OBA used a "mock" vehicle to show where it should be according to the static GTFS. If the vehicle was "live" and sending real-time data, OneBusAway presented the view of the vehicle in the route and gave the output of the prediction, whether the prediction was positive or negative.

5.2 Testing

Each program must be reevaluated and tested to verify that the implemented software is working correctly. Initially, the programs ran on a local server with more than enough capacity to satisfy each program's minimum requirements. After switching to a cloud server, each service implemented had to work in synchronicity. Traccar, Transit Clock, and OneBusAway must work simultaneously and with the nominated memory space and RAM allocated. As a result of server performance requirements, a series of tests were performed while the transit system was operational to assess the performance of each service. Traccar showed only minor issues with the cloud server. Transit Clock does not share Traccars low consumption due to its function of redirecting ports and assigning a vehicle name to incoming data. Transit Clock imports various files, including the GTFS and a bundle of the vehicles with their designated routes. One of the main reasons Transit Clock presents the most processing consumption is that Transit Clock holds most of the processing used in the implementation. Not only does Transit Clock import vehicle locations, but it also dynamically assigns a specific route to a vehicle. In addition, the service will dynamically update arrival time. In each instance where the vehicle changes location, the service automatically recalibrates and updates the arrival time. The predictive analysis in use is applied to every vehicle and updates all the moving vehicles at a specified route. If there is a vehicle but not a designated route, there is no prediction to be made. Because the GPS devices match every route in use, every GPS in use is updated. In some instances, Transit Clock stopped working or stopped giving any predictive output and analysis because the program reached the specified data usage.

Once Transit Clock was running simultaneously with Traccar, the implementation of OneBusAway was tested. The three programs are running simultaneously with Docker. After adjusting each program's memory allocation, OneBusAway needed to receive the indicated ports from Transit Clock and Traccar successfully. The data required are the vehicle location and the dynamic GTFS, respectively. For the deployed system, OneBusAway seeks to generate Transit Clock data information. Also, the visualized data from Transit Clock, such as the generated routes, stop prediction, and vehicle location, are imported to OneBusAway. The service of Traccar is used for Transit Clock but will not be directly used with OneBusAway. Once OneBusAway has generated the necessary data and files, a link will be generated, added to the OneBusAway mobile application. After adding the generated link to the application, OneBusAway is updated, showing the Mayagüez Transit System routes and vehicle locations on the devices' screens.

5.3 Deployment

After the three systems were tested and performing as needed, the team tested each application's final state. These tests dictated how efficiently the programs operated. The initial test was performed with Traccar; an example is shown in Figure 31.
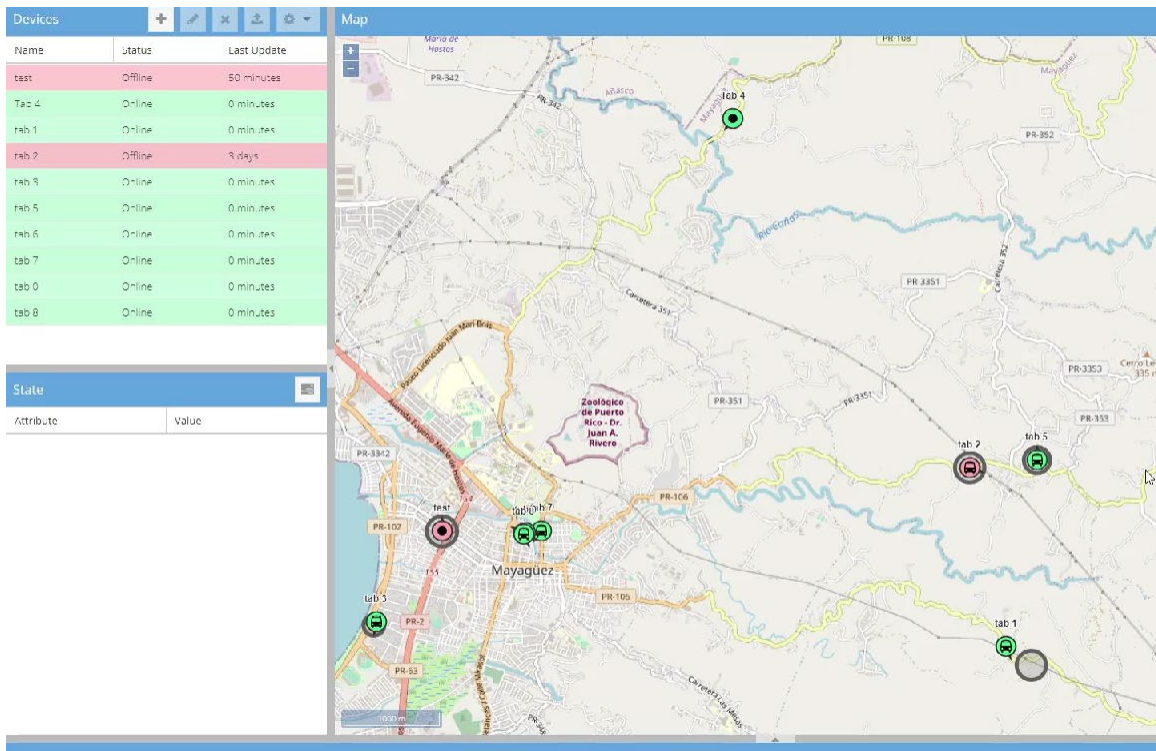

Figure 31. Traccar instance showing vehicle locations.
Source: Deployed Traccar

As seen in Figure 31, the green items in the list on the left reference the online device, each with its timestamp of the last recorded time of update. On the other hand, on the bottom right of the figure, an inconsistency with a GPS unit was observed. While the green bus icon is shown, it is not on top of the gray circle, as it should be. The circle represents the range of errors of the coordinates. In this case, the inconsistency is proof that the vehicle is updating the respective GPS.

Once Traccar is seen as a working software and functioning alongside Transit Clock and OneBusAway, the Transit Clock instance is tested for predictive accuracy, accurate mapping of the GTFS routes, and the map representation of errors in the GPS. The first test to verify the performance of the Transit Clock predictions is the evaluation presented in Figure 32. This figure shows the percentage of the predictions made vs. the length of the prediction. In other words, the graph interprets the relationship between the arrival time predicted (in minutes) and whether the vehicle arrives at the stop before, on, or after the expected time. The graph shows the range between the moments when the vehicle arrived early, on time, or later than the

50

estimated time. When interpreting the results presented in the graphs, it can be noted that the further the vehicle is, or the longer the arrival time predicted is, the less accurate it is. In some instances, these values are related to a GPS error whose coordinates are still processing, meaning that the graph is showing both correct and incorrect GPS coordinates. Without taking the GPS immediate processing into account, the graph shows that most of the arrival time predictions between 5 and 10 minutes indicate that the vehicle arrived more than a minute earlier. In comparison, when a prediction of zero to three minutes is established, the graph shows that the vehicle arrives as predicted. This situation is also present when observing Figure 33.
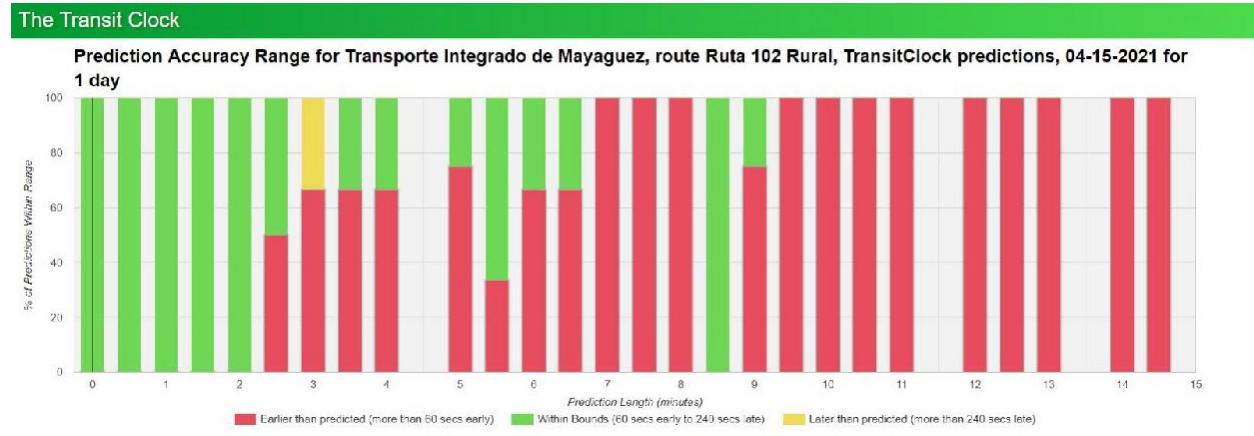
Figure 32. Transit Clock generated prediction for bus route 102 Rural, showing prediction within a given range vs prediction length.
Source: Transit Clock
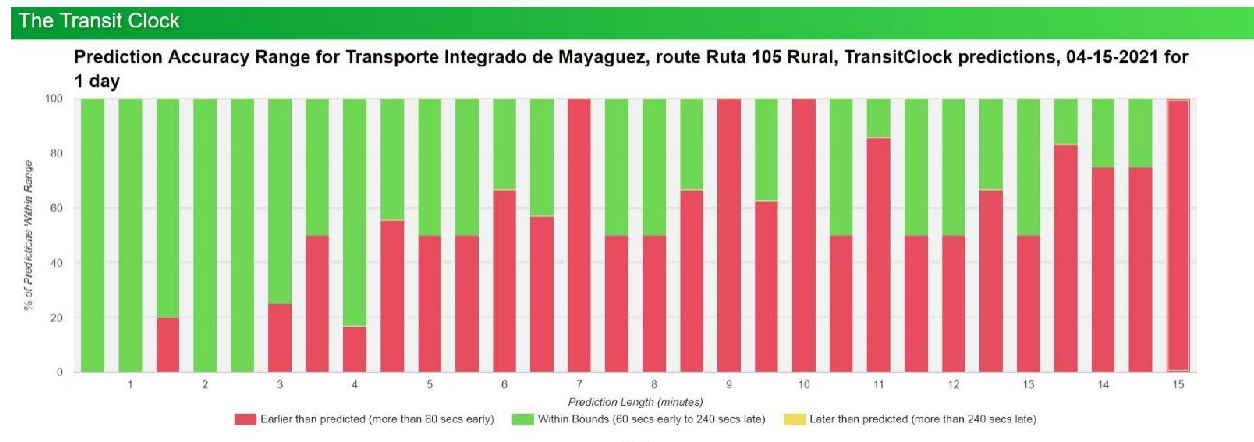
Figure 33. Transit Clock generated prediction for bus route 106 Rural, showing prediction within a given range vs prediction length.
Source: Transit Clock

Aside from the predictive analysis, Figure 34 presents the time lapse of GPS units on the different routes. Figure 35 shows the arrival time of a bus location with the error range of the GPS signal. While Figure 34 shows the specific errors of the GPS location when updated, Figure

35 shows how the error range of the GPS signal fluctuates in real time. When comparing the information presented in Figure 34 and Figure 35, a difference can be observed between the actual location of the routes and the GPS coordinates seen in Figure 34. This contrast shows both rural and urban routes and the difference between the GPS signal in both environments. When the routes are observed in groups and are seen together unifying in the public transit terminal, it can be observed that the GPS does not reflect significant differences in location. In contrast, when following the routes that are spread out and leaving the urban area, the GPS signal weakens and lacks consistency.
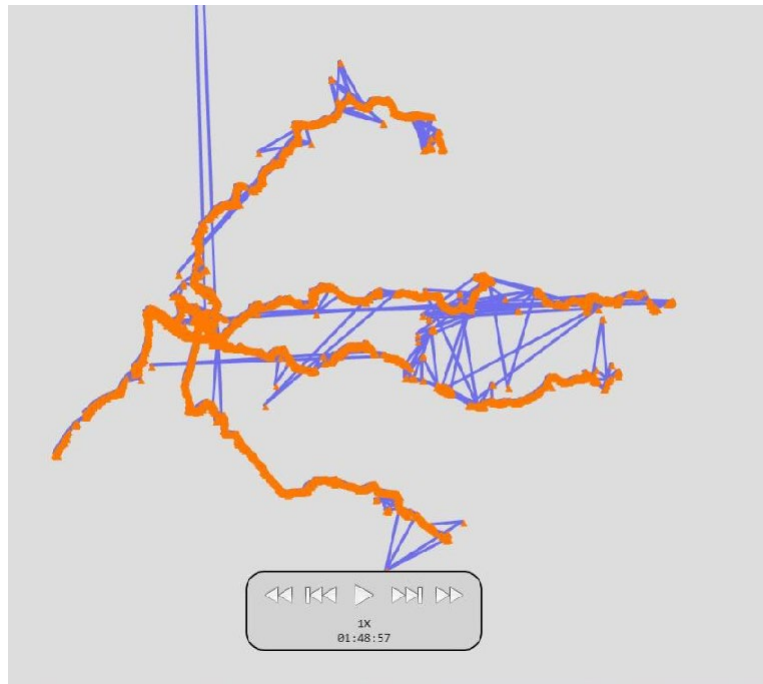
Figure 34. Transit Clock showing a time lapse of the different GPS units through the routes.
Source: Transit Clock
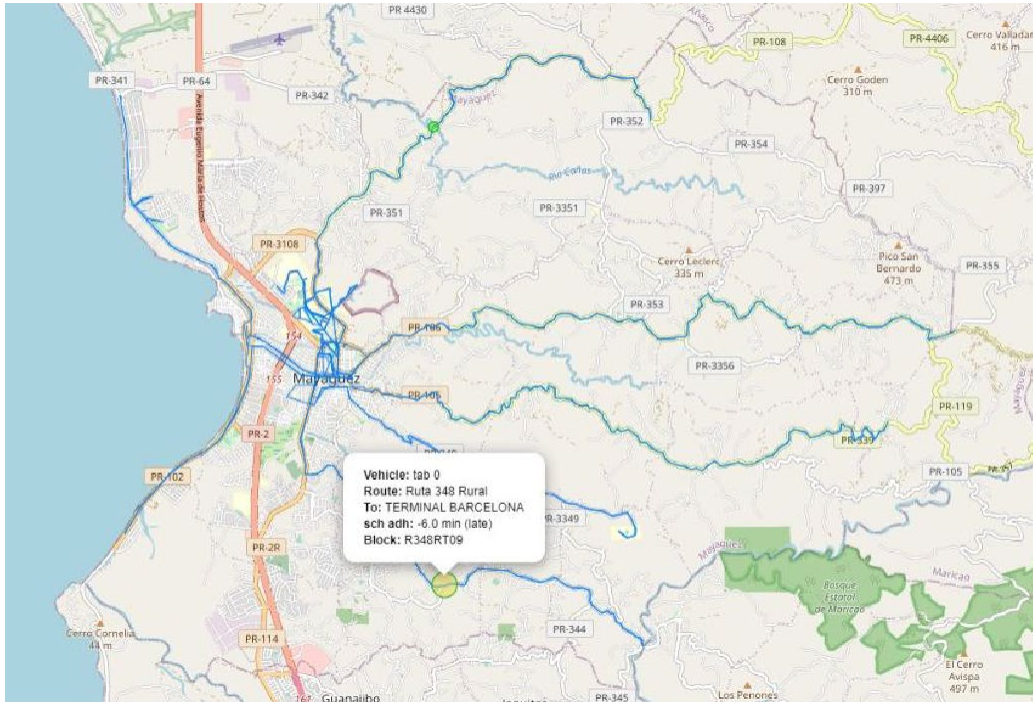
Figure 35. Transit Clock showing an overview of every route in the GTFS and a given prediction of a GPS unit.

Source: Transit Clock

Once the Transit Clock predictions and the GPS location consistency are evaluated, OneBusAway will implement the data generated. Figure 36 presents the OneBusAway screen on a mobile device. This figure shows the predictions calculated by Transit Clock and the names of the stops of the selected route. This image then shows that the unification of Transit Clock and OneBusAway was successful. In addition, the green location icon shown in the route represents the current vehicle in use for the route. This image is also proof that the unification of both Traccar and Transit Clock is successful, and as a result, so is the OneBusAway implementation. In the arrival time prediction description, a difference can be observed between the estimated arrival time set to "NOW" and the itinerary arrival time, set to six minutes before the predicted time. This arrival time prediction is an essential feature of OneBusAway because it allows us to visualize the difference between the actual arrival time and the planned arrival time.
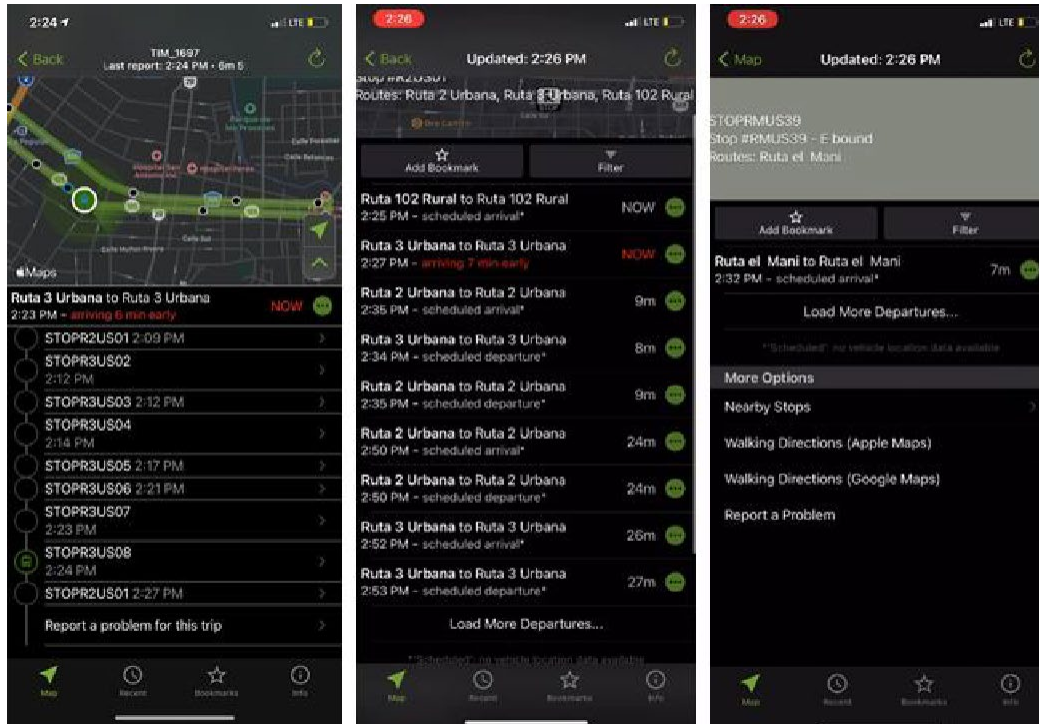
Figure 36. OneBusAway showing a route, it is designated stops and predictions.
Source: OneBusAway mobile

As a result of the successful preparation of the implementation, testing, and deployment, the system correctly represents a bus unit that has used the tracking system of Traccar, the prediction system of Transit Clock, and the user visualization system of OneBusAway. These three programs were tested and improved to specify the needs of the Mayagüez Transit System. After a successful tracking system and predictive analysis, a user can see the representation of a smart transportation system.

The figures previously shown present the predicted accuracy of each vehicle. The given graph by Transit Clock is generated each time a vehicle arrives at a stop. Every 20 seconds a prediction is made for every following stop in relation to the vehicle attached to the route. The further away the vehicle is from the stop, the less accurate the prediction. As the vehicle gets closer to the stop, the prediction of the arrival time is more accurate.

6. Conclusions and Recommendations

This research project aimed to improve the Mayagüez Transit System, known as TIM for its acronym in Spanish, and increase its ridership by providing the users with real-time information on bus arrival through a mobile phone application. The platform selected for implementation was OneBusAway which runs with Traccar and Transit Clock, all open-source programs. A series of tests were performed to identify the GPS unit most suitable for this project. It was determined that a Samsung A tablet was the best choice to install in the vehicles to generate the vehicle's location using its GPS unit. It presented fewer errors and complied with the bus operators' requirement of easiness of installation and removal. A summary of the findings obtained throughout the development of this research project is provided:

- The formatting of the GTFS files must follow the recommendation of the GTFS Best Practices. The use of testing programs for GTFS provided excellent insights during the debugging and testing processes.
- The text files that correspond to the routes' shapes are critical for the success of the system implementation.
- OneBusAway does more than simply present users with the location of buses in the street network. It is also capable of implementing modern technology to improve transportation systems further.
- The development of the research project reflects the nature of open-source software: implementing a program developed and nurtured by hundreds of programmers to benefit society.
- OneBusAway seeks to improve the way the general public perceives public transportation.

OBA implementation in a populated urban city like New York, which has a critical dependency on public transit, has improved the information and communication system with users in general. In Mayagüez, Puerto Rico, the implementation of OBA might not seem like a drastic change regarding its public transportation system. Nonetheless, the users will have an information tool to make the system reliable and appealing. The implementation of OneBusAway could lead to fewer cars, less crowded streets, and most importantly, more efficient and reliable transportation systems.

The system is not infallible. The transmission of the data from the GPS can be affected by a network signal loss or heavy rain due to less visibility of the satellites that transmit the sensors' geographical location. One of the key developments and improvements made in the research was the development of the GTFS. The information on how to prepare GTFS is scattered and requires practice preparing these types of files. Also, some GTFS examples of cities that have implemented real-time transit information applications were tested. Errors, such as routes overlapping and straight lines connecting non-adjacent stops over the map, were overcome. The reevaluation, testing, developing, and debugging of the GTFS were crucial for Transit Clock and OneBusAway.

Based on the observations recollected during the testing phase of the research projects, the following recommendations were identified:

55

- All the bus stops of the system must have a unique identification number (ID) for all the systems.
- It is recommended that the schedule be as close as possible to the actual itinerary. This feature will ensure better adherence to the predictions made by the programs.
- In order to ensure a good operation, it is recommended that in the text file corresponding to the shapes, one direction of flow be separated from the other one.
- It is recommended that the points that make up the sequence to obtain the shape of the route line be in order. The line starting point should be located at the terminal where the operation begins and the ending point at the last stop on the route.
- For a fast configuration of the GTFS files, it is recommended to elaborate a programming routine to format the information according to the GTFS Best Practices.

Acknowledgments

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